N 70 41469

CR 102823

USE OF THE BEN FRANKLIN SUBMERSIBLE AS A SPACE STATION ANALOG

Volume V – Maintainability
OSR-70-8

Prepared for
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Advanced Systems Office

Contract NAS 8-30172

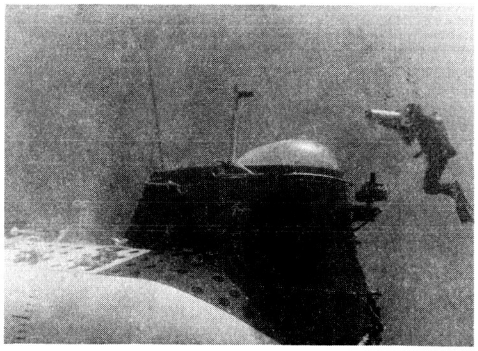
Prepared by
Space Station Analog Study Team

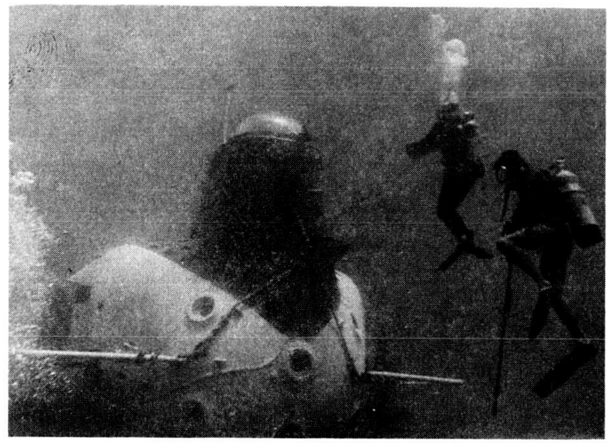
APPROVED BY M J Ferguson
M. J. FERGUSON, *Study Manager*

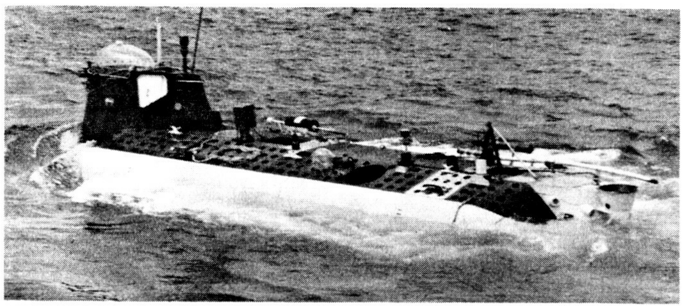
May 1970

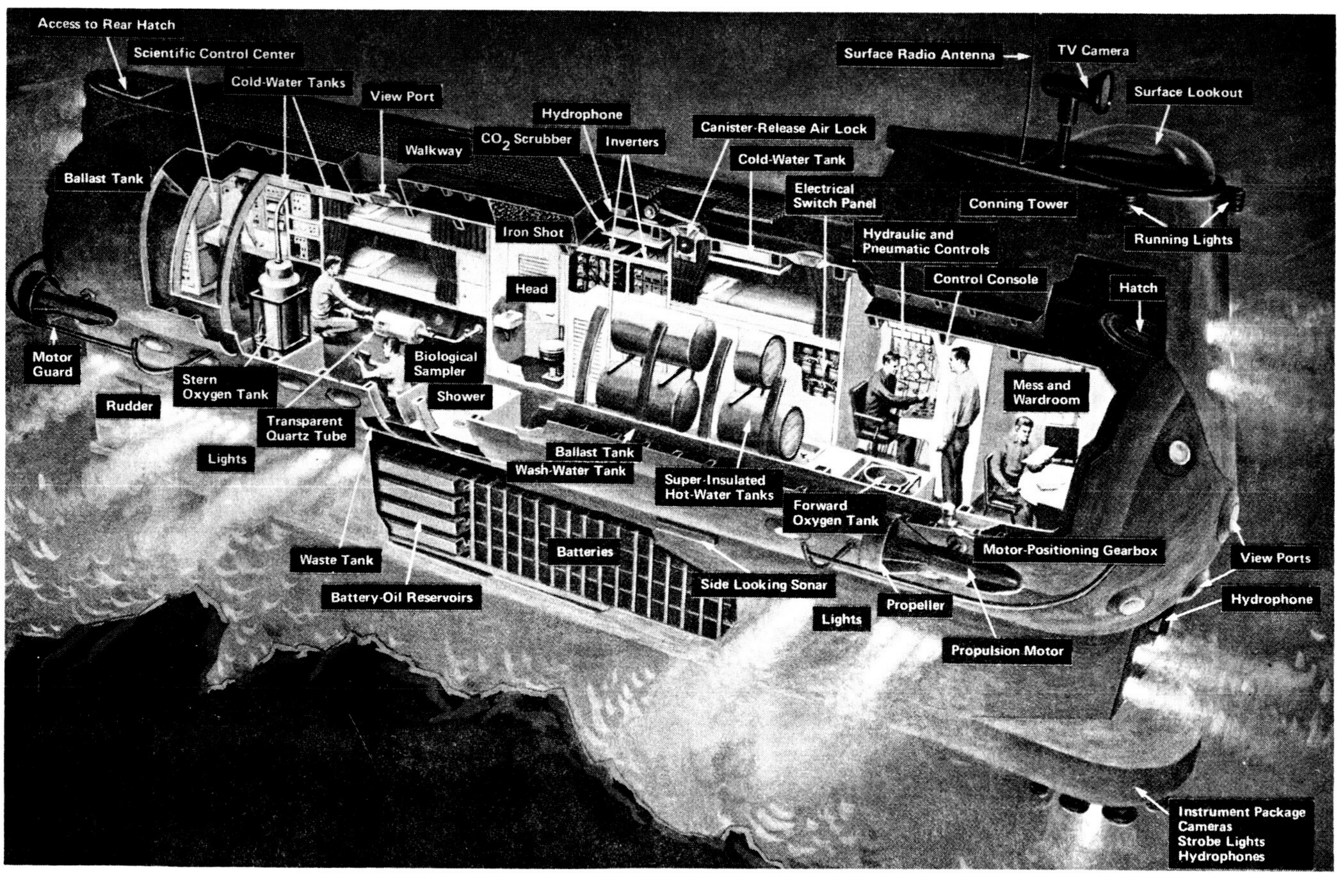
GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

THE BEN FRANKLIN DURING THE GULF STREAM DRIFT MISSION









FOREWORD

During 1969, the Ocean Systems Department of Grumman Aerospace Corporation conducted the 30-day Gulf Stream Drift Mission, using the BEN FRANKLIN submersible. As a part of this mission, a NASA study was conducted to investigate man related activities which are analogous to long-duration space station missions. During the mission, a NASA crew member was aboard the BEN FRANKLIN for data collection, observation, and task participation. This work was performed in accordance with the Statement of Work in NASA Contract NAS 8-30172, "Use of BEN FRANKLIN as a Space Station Analog," for the George C. Marshall Space Flight Center, Advanced Systems Office, under the direction of C.B. May. The program was coordinated by Manager M. F. Markey of NASA, Washington Headquarters.

The Final Report consists of the following five volumes:

- OSR-70-4, Volume I, Summary Technical Report
- OSR-70-5, Volume II, Psychology and Physiology
- OSR-70-6, Volume III, Habitability
- OSR-70-7, Volume IV, Microbiology
- OSR-70-8, Volume V, Maintainability

CONTRIBUTORS

Contributors to this study were:

Dr. Milton Delucchi	NASA, Manned Space
Mr. I. Donenfeld	Naval Medical Research
E. Dougherty, Ph.D.	Naval Medical Research
Mr. E. Fisher	NASA, Marshall Space Flight
Dr. J. Frost	Baylor University
Mr. W. Funston	NASA, Marshall Space Flight
B. A. Gropper, Ph.D.	Bellcomm, Consultant for NASA
W. W. Haythorn, Ph.D.	Naval Medical Research
Mr. R. Heckman	NASA, Marshall Space Flight (Backup crew member)
Mr. A. C. Krupnick	NASA, Marshall Space Flight
E. J. McLaughlin, Ph.D.	NASA, Space Medicine
Dr. J. N. Scow	NASA, Langley Research
Dr. S. Smith	Naval Medical Research
W. W. Umbreit, Ph.D.	Rutgers University

ABSTRACT

This report presents the NASA effort using the BEN FRANKLIN submersible as a space station analog during the 30-day Drift Mission in the Gulf Stream, starting July 14 and ending August 14, 1969. The areas of investigation include:

- Psychological and Physiological measurements during the pre-mission, mission, and post-mission phases
- Habitability in a closed ecosystem
- Microbiological evaluation of the water system, human flora, and environmental samples
- Maintainability considerations for scheduled and unscheduled tasks.

AUTHOR CREDIT

The five volumes were prepared by the Space Station Analog Team as follows:

Subject	Author(s)
• Psychology and Physiology	C. P. Seitz, Ph. D.; A. Goldman, Ph. D.; R. J. Del Vecchio, Ph. D.; C. J. Phillips, Ph. D.
• Medical	R. P. Jessup, M.D.; R. Fagin, M.D.
• Habitability	
- Habitability Analysis	M. J. Ferguson
- Environmenta`	F. Abeles, N. Kameno
• Microbiology	D. Valentine, K. Feindler, R.F. Davis
• Maintainability	J. R. Kappler, R. Toussaint
• Oceanographic Experiments	H. Reichel
• Summary	M. J. Ferguson

CONTENTS

CONTENTS (Cont)

ILLUSTRATIONS

SECTION 1

INTRODUCTION

This is the final report of the NASA Maintainability Experiment using the BEN FRANKLIN as a space station analog during the 30-day Gulf Stream Drift Mission (GSDM). The GSDM presented a unique opportunity to perform a maintainability experiment that would be useful in planning for maintainability in future space vehicles. * The intent of the experiment was to obtain insight into maintainance performed in an isolated/confined environment and apply this insight when planning for maintainability in future space vehicles.

This report presents the entire Maintainability Experiment including the planning stages, the detailed mission data analysis, and the summary of conclusions.

----

*Refer to Appendix A for the background on the importance of maintainability to long-duration space missions.

SECTION 2

OBJECTIVES

The following basic overall objectives were established for the NASA Maintainability Experiment performed aboard the BEN FRANKLIN:

- Obtain an insight into problems of providing for onboard maintenance
- Determine the impact of maintainability on mission success.

In addition, the following specific technical objectives were established:

- Evaluate the effectiveness of current aircraft maintainability analysis and prediction techniques
- Determine the maintenance workload expended during the mission
- Determine the maintenance workload distribution
- Determine the differences, if any, between maintenance performed in stressed versus unstressed environments
- Investigate the effects of training, learning, skills, spares, tools, test equipment, and technical information on maintenance performed during the mission.

SECTION 3

DATA ACQUISITION AND TECHNIQUES

The actual performance data from the mission and from the dock-side baseline time trials were intended to be the major source of information used to determine the effectiveness of the Maintainability Experiment. Therefore, it was of paramount importance that each data source be identified and those data be collected as effectively as possible. In reviewing the experiment objectives, it became evident that there was a need for two different types of feedback information.

The first or qualitative type of information involved the recording of subjective crew opinions and descriptions of maintenance actions performed. From this information, it was possible to obtain an insight into the effects of: skill levels, training, technical data availability, learning, maintenance workloads, special maintenance procedures, spares provisioning, tool provisioning, quick reference check lists, and the environment. This type of information was obtained from the following areas:

- Ship's Log
- Captain's Log
- Communications Log
- Crew Member's (NASA) Log
- Crew Debriefings.

Before the mission, each of the log books was prepared with special formats to facilitate recording of the desired information. The NASA crewman's log was designed to record chronological narratives of daily events. This was augmented by a mission calendar day file of scheduled maintenance data sheets* arranged in the order of expected usage, Day 1 through 30.

---

*Refer to Appendix C for data sheets included with the maintenance procedures.

The second type of required data was quantitative, such as the elapsed times to perform the basic elements of each maintenance task. Accordingly, a special NASA Maintenance Report Log Book was devised with easy entry forms to record the elapsed time for each maintenance task element*. Another source of quantitative data was the film which provided a record of crew activities every 2 minutes during the mission.

The NASA crew member had the responsibility to document all scheduled and unscheduled maintenance accomplished during the mission. The Maintenance Report Form provided entries for the amount of time required to complete service and repair actions, special problems associated with repairs, and the working conditions under which the maintenance task was performed. The report was divided into two sections, one on each side of the form. The front side of the form was for recording objective data, such as equipment failure, cause, parts replaced, method of troubleshooting and the amount of time required to perform each element of the maintenance action. The reverse side of the form provided for a quick recording of subjective information, such as the difficulties caused by equipment design or working conditions, hazards, physical limitations, etc.

The Maintenance Report Form was designed to aid in the evaluation of the two most promising prediction techniques. On the front of the form, the layout and the type of information was such that it could easily be compared to the results of Method II of MIL-HDBK-472; on the reverse side, the information was arranged so it could easily be compared with Method III of MIL-HDBK-472. These two methods have been successfully employed on various aircraft programs and offer the most promising techniques for space application.

To make as complete and as comprehensive an analysis as possible and to gather as much available data as possible, crew debriefings were held immediately after the mission. These debriefing sessions permitted a detailed review of all logs and a verbal summary of all events which occurred during the mission. These sessions were also useful for clarification of data entries and for obtaining the rationale behind actions taken or omitted during the mission.

----

*Refer to Appendix E for Maintenance Report Forms.

SECTION 4
MISSION PLANNING

Measurable milestones were considered absolutely essential to the completion of the pre-mission tasks prior to the departure date, as well as for timely completion of the post-mission tasks.

Accordingly, the NASA Maintainability Experiment was accomplished in 11 distinct phases:

- Phase I - Definition of Work Scope for the Experiment
- Phase II - Documentation of the Controlled Maintenance Tasks
- Phase III - Cognizant Engineer Review of Controlled Maintenance Tasks
- Phase IV - Project Management Review of Experiment
- Phase V - Maintainability Analysis and Prediction
- Phase VI - Assembly of NASA Maintainability Experiment Workbook
- Phase VII - Drift Mission Crew Review and Familiarization
- Phase VIII - Dock-Side Time Trials
- Phase IX - Mission Performance Data Recording
- Phase X - Crew Debriefing, Data Reduction, and Analysis
- Phase XI - Preparation of Final Report.

Appendix B gives detailed breakdown and description of all phases of the program plan, as well as the experiment plan.

SECTION 5

MAINTAINABILITY ANALYSIS AND PREDICTION TECHNIQUES

Maintainability analysis and prediction techniques provide the means for estimating the elapsed time and man-hours required to maintain a given system or set of equipment. These techniques provide a "measuring stick" with which various design approaches can be evaluated for their ultimate maintenance workload and skill level requirements. The techniques not only permit the maintainability engineer to evaluate a design during development, but also permit him to pin point any areas of poor maintainability. This in turn helps to justify design improvements, modifications, and revised design approaches. Another useful feature of the analysis and prediction technique is the relative ease with which an engineer can obtain an early assessment of the feasibility of the: predicted down-times, quantity and quality of personnel, tools, test equipment, and spares required for a given system design on a particular mission.

These analysis and prediction techniques have been refined to a high degree for use on aircraft programs. It became necessary to determine if these techniques were fully applicable and effective when used on space equipment in a space-type environment. As a result of the NASA Maintainability Experiment, it was possible to test these various techniques on a space-type mission and to determine their relative merits with an identification of the factors that may have caused variations from an aircraft-type application.

A major objective of any maintainability program is to ensure that if a man-maintained system malfunctions, it can be restored to serviceable condition within a specified period of time. This objective is usually stated quantitatively for each system or set of equipment.

The maintainability engineer is normally charged with the responsibility for meeting specific requirements which include:

- A Mean Time To Repair (MTTR) for each significant equipment component, subsystem, system, and the entire vehicle, as required
- Built-in-test (BIT) or Onboard Checkout (OBC) requirements for equipment sets, subsystems, systems, and the entire vehicle
- Confidence levels specified for the onboard fault detection and fault isolation capabilities of BIT and OBC
- Maintenance workload maximums specified for the vehicle as man-hours per operating hour
- Design commonality and interchangeability requirements
- Level of maintenance requirements consistent with overall vehicle weight, cost, and performance requirements.

Maintainability predictions are used to forecast equipment maintenance operations resulting from a given design. These estimates are a direct indication of the extent to which the specific equipment designs are contributing to the cost of maintaining the vehicle in a given mission. Prediction techniques should be applicable to any maintainable equipment whether it is an aircraft, a submersible, or a spacecraft.

Various prediction techniques have been developed by industry and the military which give reasonably accurate quantitative estimates of the time required to maintain equipment in typical aircraft or naval vehicles. To the best of our knowledge, no one, up to this point, has developed a unique prediction technique for application to spacecraft design.

At present, the few standard methods that have been accepted by industry and the military differ widely in their approach and technique. Four basic methods have been classified and explained in considerable detail in MIL-HDBK-472. (These methods are outlined in Appendix D.) Of the four, the two most suitable techniques, Methods II and III, were evaluated for this experiment. Method II, which was found to be the most accurate and dependable, is discussed in Subsection 7.4 of this report.

SECTION 6

PRE-MISSION CREW TRAINING

Pre-mission crew training was included as part of the NASA Maintainability Experiment. The recommended maintenance procedures for the equipment were reviewed and discussed during a series of training sessions.

These training sessions were scheduled to accomodate the individual schedules of the crew members. The sessions were of three general types:

1. Review of Ship Systems and Equipment - Each of the ship systems was studied for function, operation, equipment identification, and location

2. Review of the Maintenance Procedures - Each of the 27 controlled maintenance procedures were studied to be certain that the purpose and details were understood, including the use of check lists, charts, data sheets, spares, tools, and test equipment

3. Crew Demonstration and Dock-side Time Trials - Crew members concerned with maintenance of the equipment covered by the NASA Experiment were required to perform each task on the vessel. The elapsed times recorded during these trials were used to establish the baseline time data for the maintenance actions.

Training session types 1 and 2 were accomplished as planned. The emphasis was placed on the first type since each of the crew members had to become thoroughly familiar with the operation of the vessel and its systems.

Completion of training session type 3 proved to be more difficult to accomplish than originally anticipated. This was primarily due to the last-minute outfitting and checkout of the vessel and its equipment prior to departure. However, every task was performed at least once prior to departure. Several of the time trials had to be accomplished by an engineer, with a background similar to a particular crew member, when the crew member was unavailable. In some instances, a portion of a time trial or demonstration had to be simulated when it involved disassembly of equipment that had already been checked out for the mission.

SECTION 7

DATA ANALYSIS

7.1 GENERAL

To ascertain whether the experiment objectives were met, the analysis task was organized and developed for inquiry into three basic areas:

- Maintenance Manpower Distribution
- Maintenance Task Analysis
- Prediction Technique Evaluation.

While the controlled maintenance tasks were the central core of the experiment, they did not cover all of the onboard equipment. A significant amount of maintenance occurred on the NAVOCEANO equipment which was not included in the controlled portion of the experiment.

The NASA Representative was the only person designated to file the maintenance report forms. There were six watches per day; therefore, approximately 50% of each day was not covered by the trained maintenance observer. Despite this handicap, most of the maintenance performed on the controlled equipment was timed and recorded.

As a result of the debriefing interviews and detailed log investigations, it became possible to include unreported maintenance actions. Each log book was examined in detail, the NASA films were reviewed, and a series of personal meetings were held with each crew member to identify the unreported maintenance tasks. This resulted in positive identification of 1310 unreported maintenance actions which in turn permitted determination of the manpower expended in these tasks.

The reported data and the information obtained from log books, notes, NASA films, and crew debriefing were compiled into a Maintenance Action Summary (Figure 7-1). This summary lists all of the readily identifiable maintenance tasks accomplished during

MAINTENANCE ACTION SUMMARY

Task No.	Date	Maintenance Action	Scheduled	Unscheduled	No. Actions	No. Reported	Completed	Not Completed	Task Time Min	Remarks
1	VARIOUS	S-1 BATTERY VOLTAGE & RESISTANCE TEST	X		6	6	X		15.88	
2	"	S-2 PENETRATOR INSPECTION	X		240	2	X		*	* ITEMS 2,3,4, & 5 ACCOMPLISHED AS ONE ACTION, TASK TIME 8 MIN
3	"	S-3 SEA VALVE CYCLING & INSPECTION	X		240	0	X		*	
4	"	S-4 HYDRAULIC SYSTEM INSPECTION	X		240	0	X		*	
5	"	S-5 PNEUMATIC SYSTEM INSPECTION	X		240	0	X		*	
6	"	S-6 FATHOMETER SERVICING & INSPECTION	X		6	0	X		5.00	
7	"	S-7 AMP-HR CONSUMPTION CHECK	X		3	1	X		15.00	TASK WAS TERMINATED AFTER 10 DAYS

Figure 7-1. Maintenance Action Summary (Sheet 1 of 7)

MAINTENANCE ACTION SUMMARY

Task No.	Date	Maintenance Action	Scheduled	Unscheduled	No. Actions	No. Reported	Completed	Not Completed	Task Time Min	Remarks
8	VARIOUS	S-9 TAPE RECORDER SERVICING	X		30	0	X		1.50	
9	"	S-10 MEGGER CHECK PROPULSION SYS	X		5	4	X		24.30	
10	"	S-11 WATER SYS BACTERIAL FILTER REPL	X		2	2	X		28.20	
11	"	S-12 WATER SYS PURITY TEST	X		9	3	X		56.6	
12	"	S-13 HUMAN FLORA TEST	X		9	3	X		111.66	
13	"	S-13 ANDERSON AIR SAMPLER	X		9	0	X		45.00	
14	"	S-13 RODAC SURFACE TEST	X		9	3	X		73.33	
15	"	AIR CONTAMINATION TEST	X		4	0	X		35.00	

Figure 7-1. Maintenance Action Summary (Sheet 2 of 7)

MAINTENANCE ACTION SUMMARY

Task No.	Date	Maintenance Action	Scheduled	Unscheduled	No. Actions	No. Reported	Completed	Not Completed	Task Time Min	Remarks
16	VARIOUS	GAS CHROMATO-GRAPH TEST	X		2	2	X		113.00	
17	"	LiOH PANEL REPLACEMENT	X		11	0	X		16.00	
18	"	SILICA GEL REPLACEMENT	X		5	0	X		30.00	
19	"	DATA TAPE RECORDER SERVICE	X		30	0	X		5.00	DAILY CLEANING OF TAPE HEADS
20	"	POSITION DEPTH RECORDER SERVICE	X		30	0	X		5.00	DAILY CLEANING
21	8/3	SHIP DEPTH RECORDER SERVICE	X		2	0	X		5.00	DAILY CLEANING
22	VARIOUS	U-1 FUSE REPLACEMENT		X	10	4	X		8.00	
23	7/17	U-3 MACERATOR MOTOR WIRING		X	1	1	X		220.00	

Figure 7-1. Maintenance Action Summary (Sheet 3 of 7)

MAINTENANCE ACTION SUMMARY

Task No.	Date	Maintenance Action	Scheduled	Unscheduled	No. Actions	No. Reported	Completed	Not Completed	Task Time Min	Remarks
24	8/12	U-3 MACERATOR MOTOR SWITCH		X	1	1		X	5.0	OCCURRED AT END OF MISSION - NOT MISSION CRITICAL
25	7/27	U-8 EGAN EXPERIMENT		X	1	1		X		NOT MISSION CRITICAL
26	7/30	STERILIZATION OF SURFACES		X		1	X			NO TIME RECORDED
27	7/14	FATHOMETER FAILURE		X	1	0		X		FAILURE OF EX-TERNAL SENSOR
28	7/14	SUB BOTTOM PROFILER FAILURE		X	1	0		X		FAILURE OF EX-TERNAL SENSOR
29	7/14	MAGNETOMETER		X	1	0		X		FAILURE OF EX-TERNAL SENSOR
30	7/18	SHIP COMPASS FAILURE		X	1	0		X		FAILURE OF EX-TERNAL SENSOR

Figure 7-1. Maintenance Action Summary (Sheet 4 of 7)

MAINTENANCE ACTION SUMMARY

Task No.	Date	Maintenance Action	Scheduled	Unscheduled	No. Actions	No. Reported	Completed	Not Completed	Task Time Min	Remarks
31	7/14	LIGHT TRANSMISSOMETER		X	1	0		X		FAILURE OF EX-TERNAL SENSOR
32	7/30	SLEEP MONITOR POWER DISRUPT		X	1	1	X		8.00	POWER DISCON-NECTED TO REMOVE POWER FAILURE
33	8/2	SLEEP MONITOR SENSOR FAILURE		X	1	1	X		210.00	
34	7/17	COMMODE HANDLE REPAIR		X	1	1	X		8.00	
35	7/15	AUX INVERTER FAN SERVICING		X	1	1	X		126.00	
36	7/29	RELOCATION OF FLOOR COUNTER		X	1	1	X		48.00	REDESIGN OF SCIENTIFIC EX-PERIMENT
37	7/17	CLOGGED SHOWER SINK		X	1	1	X		4.20	

Figure 7-1. Maintenance Action Summary (Sheet 5 of 7)

MAINTENANCE ACTION SUMMARY

Task No.	Date	Maintenance Action	Scheduled	Unscheduled	No. Actions	No. Reported	Completed	Not Completed	Task Time Min	Remarks
38	8/3	CURRENT METER FAILURE		X	1	1		X	-	FAILURE OF EXTERNAL SENSOR
39	7/17	NAVOCEANO 70-MM CAMERA		X	1	0		X	-	FAILURE OF EXTERNAL SENSOR
40	8/11	JAMMED BEARING TAPE RECORDER		X	1	1	X		107.0	
41	7/15	HG PENETRATOR LEAK		X	3	0	X		-	NO TIME RECORDED
42	7/15	AIR PRESSURE REGULATOR LEAK		X	1	0	X		-	NO TIME RECORDED
43	7/20	PULSEMETER BATTERY RECHARGE		X	2	0	X		-	NO TIME RECORDED
44	7/15	OIL LEAK SHALLOW DEPTH GAGE		X	1	0	X		-	NO TIME RECORDED
45	7/15	CO_2 GAGE MALFUNCTION		X	1	0		X	-	NO SPARES

Figure 7-1. Maintenance Action Summary (Sheet 6 of 7)

MAINTENANCE ACTION SUMMARY

Task No.	Date	Maintenance Action	Scheduled	Unscheduled	No. Actions	No. Reported	Completed	Not Completed	Task Time Min	Remarks
46	7/16	B2 AMP-HR COUNTER FAILURE		X	1	0		X	-	NOT MISSION CRITICAL
47	8/1	POSITION DEPTH RECORDER FAILURE		X	1	0	X		730.0	EXTENSIVE CANNIBALIZATION OF SPARE
48	7/19	AFT TRIM PUMP SEIZURE		X	4	0	X		-	NO TIME RECORDED
49	7/14	SIDE SCAN SONAR		X	1	0	X			OVERVOLTAGE CONDITION OF BATTERIES
50	VARIOUS	NAVOCEANO CALIBRATIONS	X		50	0	X		*	* TOTAL CUMULATIVE TIME = 180 HRS.
51	"	NAVOCEANO SVCG. EXPERIMENTAL EQ.	X		40	0	X		*	
52	"	NAVOCEANO OPERATIONAL M CHECKOUT	X		30	0	X		*	
53	"	NAVOCEANO EXPERIMENTAL EQ. PREP.	X		30	0	X		*	
54	"	NAVOCEANO EXP. DATA TAPE HANDLING	X		30	0	X		*	

Figure 7-1. Maintenance Action Summary (Sheet 7 of 7)

the mission, the number of times each task was performed, and the elapsed time required. It was interesting to note that a total of 1354 maintenance actions were positively identified; 1310 unreported and 44 reported maintenance actions.

7.2 MANPOWER DISTRIBUTION

In determining the manpower distribution of the active maintenance workload performed over the 30-day GSDM, interest was first focused on determining the percentage of the total daily workload that was devoted to both scheduled and unscheduled maintenance. The first analysis of the Maintenance Action Summary resulted in Figure 7-2 which shows the amount of scheduled and unscheduled maintenance performed during each mission day.

The cumulative daily mission maintenance workload was determined and plotted for the total maintenance effort expended (Figure 7-3). The total cumulative maintenance workload turned out to be 321.7 man-hours, or an average of 10.7 man-hours per day. Of this total, scheduled maintenance took 268.2 man-hours, and unscheduled maintenance took the remaining 53.5 man-hours. Figures 7-2 and 7-3 provide an overview of the total maintenance workload accomplished during the entire GSDM.

The graphs indicate that the maintenance workload consisted of a minimum of 6 man-hours per day spent on routine scheduled operating maintenance. Superimposed on top of this 6 man-hour daily base was an additional cyclic scheduled maintenance workload which seemed to peak out at 8 to 9 man-hours every third day. During the first 11 days, this cyclic workload was very heavy. This indicated that the crew may have been very conscientious but tended to devote more time to scheduled maintenance on Days 2, 5, and 11, which were the mission drift periods when the BEN FRANKLIN was drifting at 600 feet in the Gulf Stream.

On Days 13 through 17, the crew attempted to adjust the scheduled maintenance workload so as to distribute the work more evenly over this 3-day cycle. From Day 18 to the end of the mission, the fluctuation in scheduled maintenance was reduced to a point satisfactory to the crew.

Deep dives were also observed to have an effect on the amount of maintenance performed on any given mission day. During the early part of the mission, the daily maintenance workload was apparently reduced on deep dive days to accommodate the increased operational workload. This indicates that the crew was able to organize and adjust its maintenance efforts to suit mission requirements. The days immediately preceding and following each dive were generally heavy maintenance days. As their experience with the dive maneuvers increased, the tendency to reschedule maintenance became less noticeable.

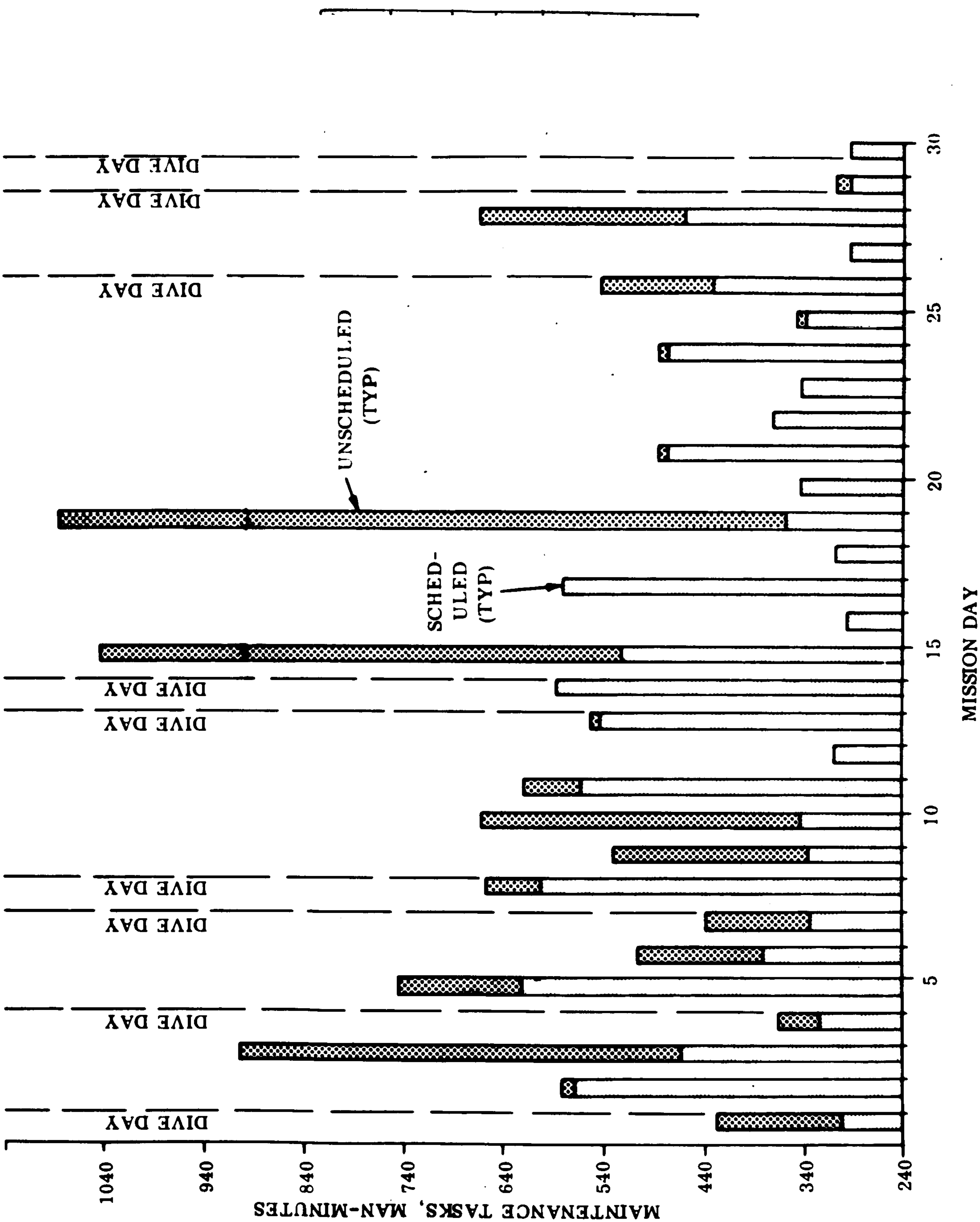


Figure 7-2. Manpower Distribution By Day

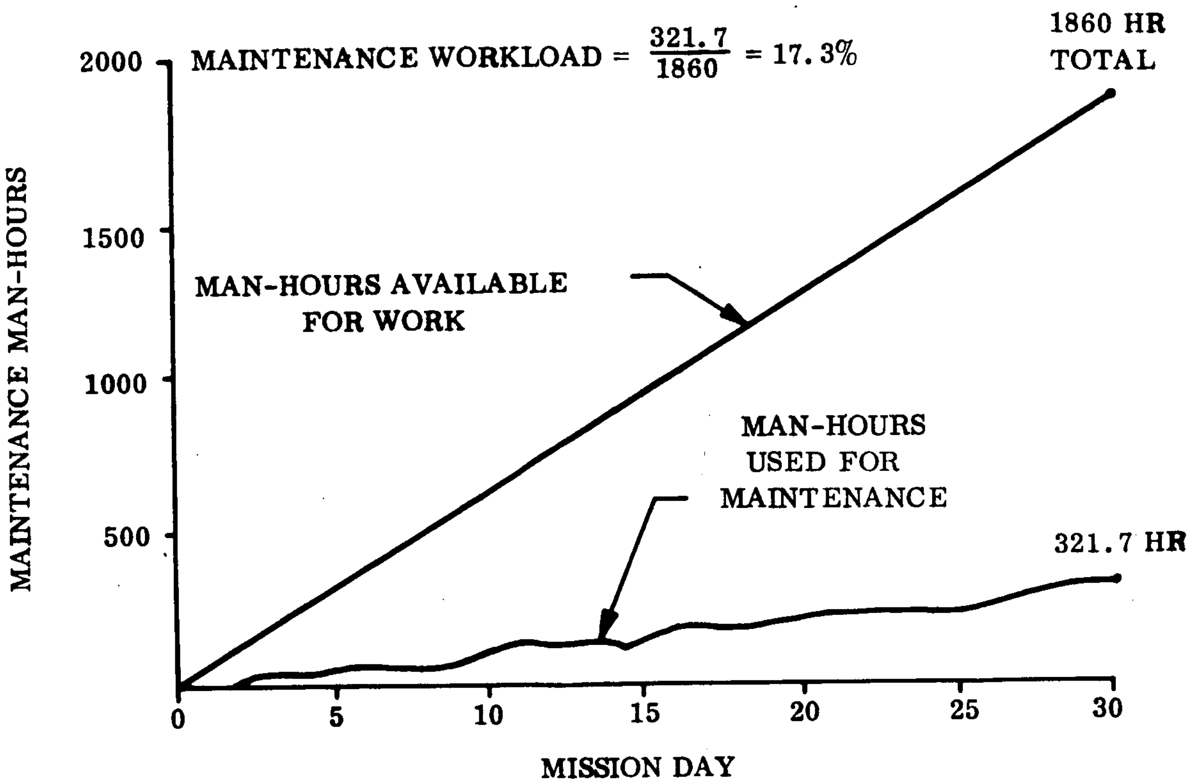


Figure 7-3. Cumulative Maintenance Workload

From Day 16 through 26, the amount of daily scheduled maintenance was lower. This lower level of maintenance activity corresponded with the mission drift period, during which there was generally a lower level of activity, especially in the oceanography area. The crew was also able to improve on the scheduled maintenance workload by combining tasks and better organization of their efforts.

The maintenance workload involved in the unscheduled maintenance activity indicated some significant trends. The first was the generally high unscheduled maintenance activity during the first-half of the mission, as compared with the last-half of the mission. During the first-half, the crew spent about 2 man-hours per day on unscheduled maintenance. During the drift period, very little unscheduled maintenance was accomplished, except for two major unscheduled repair actions. The significance of these two major repairs was that these complex repairs were deferred until there was an opportunity to devote a long uninterrupted segment of time to perform the work properly.

These observations of the maintenance workload gave an insight into the flexibility and resourcefulness of the crew since they were able to organize, modify, and adjust this workload, not only to suit operating conditions, but also to take advantage of their experience gained during the mission.

7.2.1 Maintenance Workload Compared with Total Manpower Available

To obtain a clear view of the maintenance workload as a percentage of the total available daily man-hours during the mission, a graph was constructed with both daily and 3-day workload average percentages. Figure 7-4 shows some significant trends. The daily maintenance workload varied from a low of 12% to a high of 31% of the total manpower available during any one day. The total maintenance workload was 17.3% of the total on-duty manpower available. This is approximately 1/6 of total duty time; the equivalent of one man devoted to maintenance full time.

Another significant trend is the downward slope of the 3-day average for the duration of the mission. At the beginning of the mission, the 3-day average value was approximately 20%, and gradually decreased to 14% at the end of the mission. This could be explained as the result of improved operations by the crew, decreased requirements for equipment service and repair, and postponement of maintenance repairs toward the end of mission. There was an obvious stabilization, or leveling off, of maintenance workload as indicated in Figure 7-4. The projected workload for this vessel, if it had continued beyond 30 days, would consist of the final optimized scheduled maintenance load of approximately 10% or 6.36 man-hours per day based on the trend established during the last 15 mission days.

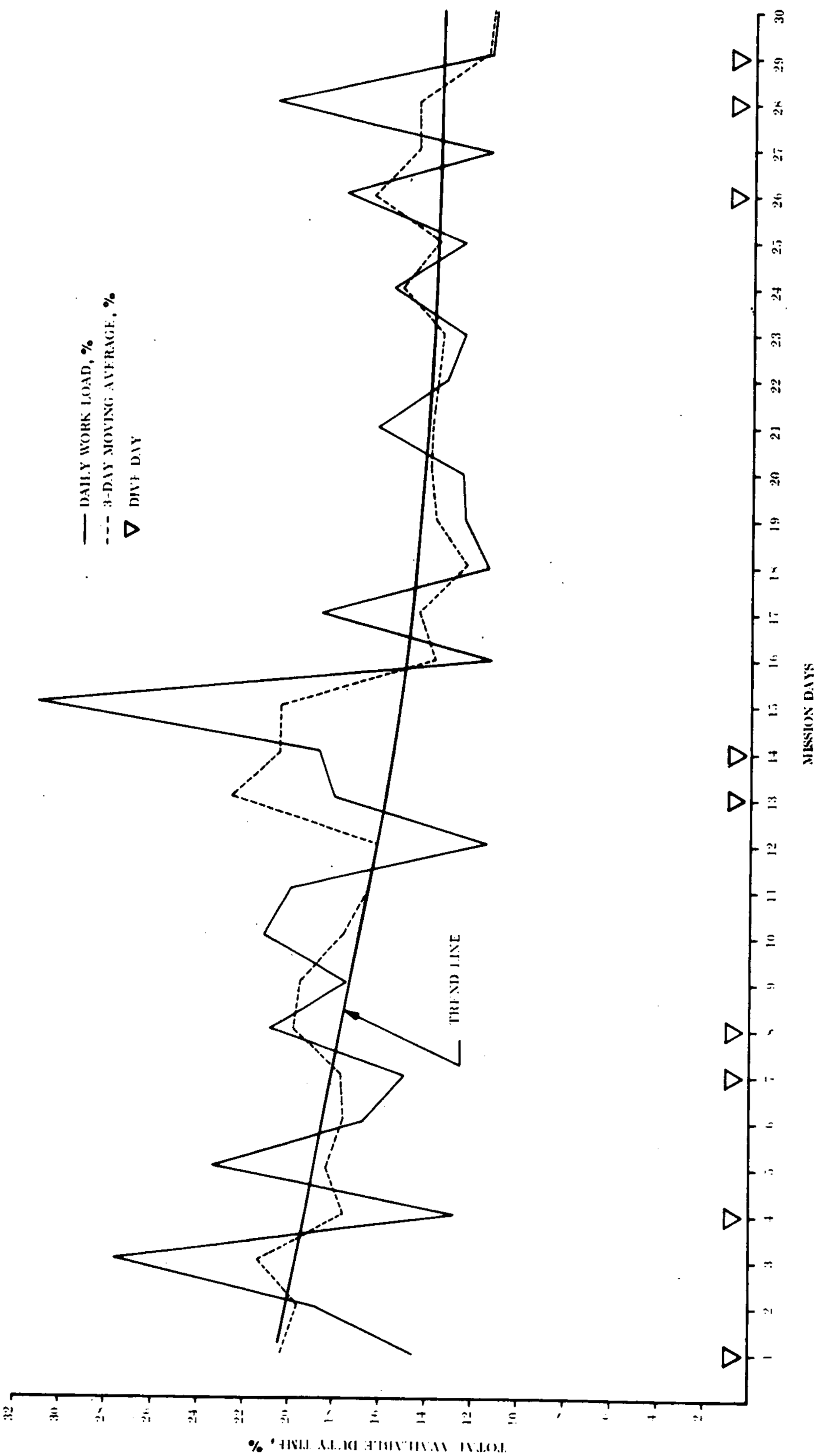


Figure 7-4. Percent Maintenance Man-Hours of Total Working Hours Per Day

The daily total projected workload for this vessel beyond 30 days would have been the basic scheduled load of 10% plus the unscheduled maintenance. For this mission, the unscheduled or maintenance repair workload was 2.87% of the total available crew duty time. This rate of repair action was reasonable for the complexity and type of equipment aboard.

Another factor that may have influenced this leveling trend was the postponement of the following 11 identified maintenance repair actions until after the mission:

Maintenance Action Task No.	Item Failure	Remarks
24	Macerator Motor Switch	Not critical
25	Light Experiment	Not critical
27	Fathometer	External sensor
28	Sub-bottom Profiler	External sensor
29	Magnetomometer	External sensor
30	Ship's Compass	External sensor
31	Light Transmissometer	External sensor
38	Ocean Current Meter	External sensor
39	NAVOCEANO 70-MM Camera	External component
45	CO_2 Gage	No spares
46	B-2 Ampere-Hour Counter	Not critical

Of the 11 postponed items, 7 could not be accomplished since the equipment was external*, 1 lacked the necessary spare, and 3 were not accomplished since they were not considered to be mission critical. One of the latter failures (No. 24) would have become mission critical if it had occurred earlier than Day 29. The switch failure caused the loss of the macerator electric sewage disposal function which was backed up by a manual pumping system.

7.2.2 Maintenance Man-Hours per Crew Member per Day

The second analysis area concentrated on was the amount and type of daily maintenance work performed by each crew member, considering his assignment, background, and training.

----

*Since the vessel was not configured for underwater egress and ingress on this mission, repairs were not possible on external equipment.

Since each crew member had a specific primary function as well as a general secondary responsibility during the mission, it was possible to code each man for analysis purposes. A matrix of identification codes and assignments was set up to permit correlation of mission data with crew function. Figure 7-5 indicates the basic assignment and the primary and secondary functions of each crew member.

Figure 7-5 shows some interesting relationships relative to crew responsibilities. All but one man had a scientific role oriented towards meeting the engineering and scientific objectives of the GSDM. Another interesting point was that all except one man had more than one function, and even at that the "pure scientist" did perform some maintenance on his own equipment.

With regard to maintenance, analysis of these data revealed some interesting observations:

- All crew members performed some scheduled maintenance on the vehicle
- All scientific crew members performed scheduled maintenance on their own scientific equipment
- Maintenance was the primary function of only one crew member
- Most of the unscheduled maintenance was performed by a skilled specialist who also took on a heavy scheduled maintenance workload
- The second heaviest unscheduled maintenance workload was performed by the crew man with the primary maintenance responsiblity.

To illustrate these observations, Figure 7-6 shows the amount of scheduled and unscheduled maintenance performed by each crew member on any given day. The profiles give an insight into the functions and maintenance responsibilities assumed by each crew member.

Crew Member No. 1 was primarily a scientist. He served as the mission leader and functioned secondarily as a member of the operation's crew. With respect to maintenance, he became involved in the scheduled inspections of the vessel's systems and equipment. The greater portion of his time was devoted to scientific observations.

Crew Member No. 2, the oceanographer-scientist, performed a steady load of operational-type scheduled maintenance on his scientific equipment which was 33.8% of all scheduled maintenance performed. His total maintenance contribution was 28.4% of the total maintenance work performed. He was not involved in maintenance operations on the vessel and its related systems or equipment.

CREW MEMBER ASSIGNMENT AND MISSION FUNCTION

Crew Member			Function	
Assignment	Code	No.	Primary	Secondary
Mission Leader	○	1	Scientific	Operations
Oceanographer	*	2	Scientific	None
Pilot	□	3	Operations	Scientific
Oceanographer	△	4	Scientific	Maintenance
Pilot	+	5	Operations	Maintenance
Engineer	⧖	6	Maintenance	Scientific

Figure 7-5. Crew Member Assignment and Mission Function

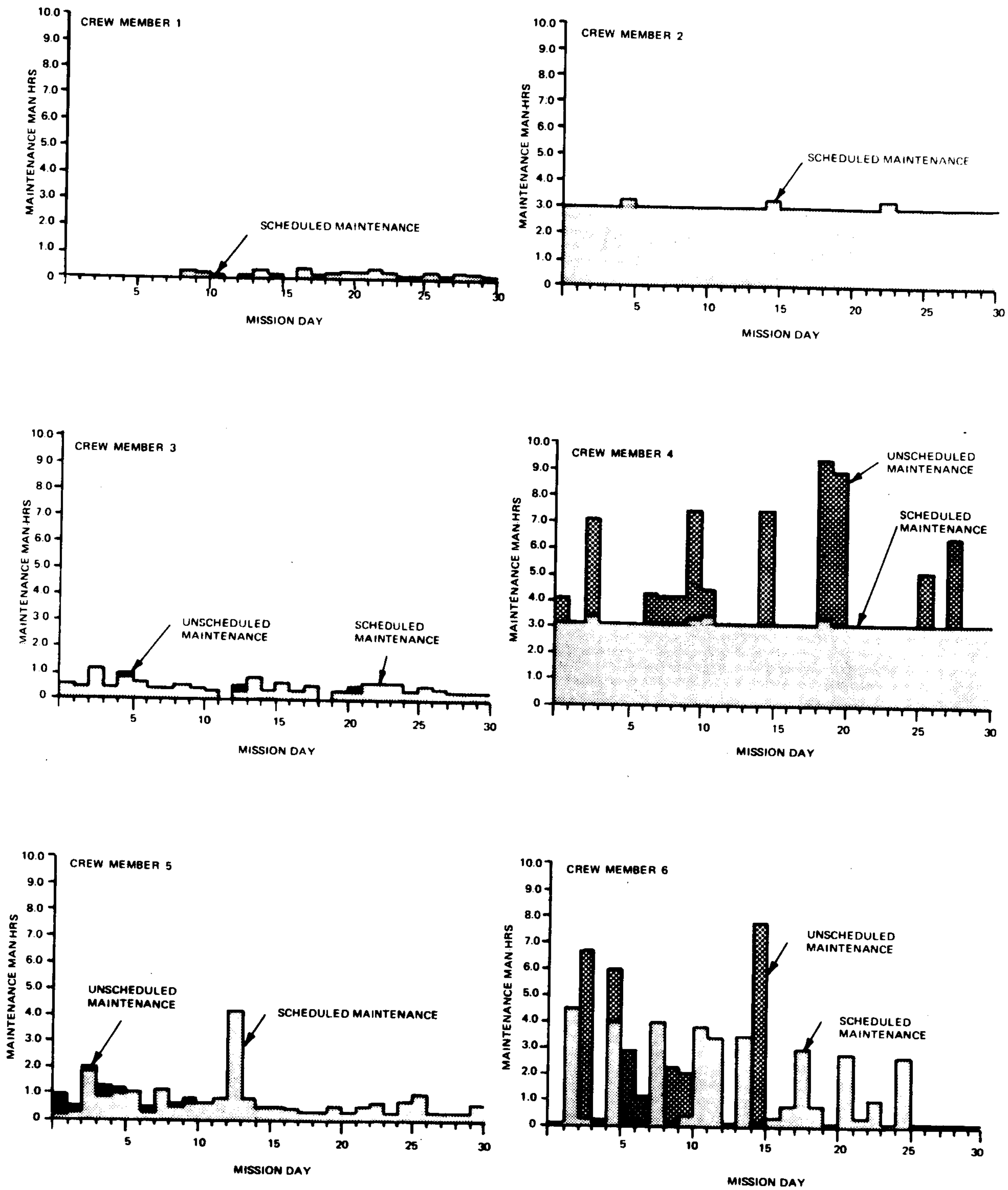


Figure 7-6. Maintenance Workload By Mission Day

Crew Member No. 3 was primarily one of the vehicle's operating pilots. His secondary function was that of a scientist. The greatest portion of his maintenance effort was devoted to scheduled maintenance items related to the vessel operation. These tasks were essentially inspection items and replacement of silica gel and lithium hydroxide panels. He was not heavily involved in the unscheduled maintenance effort because his scientific observations took precedence.

Crew Member No. 4 was primarily an oceanographer-scientist, but performed an important role in his secondary function of maintenance on both the vessel and experiment equipment. His relatively heavy scheduled maintenance workload was directly involved with the oceanography scientific experiment equipment. Analysis revealed that he functioned as the prime mover in almost every unscheduled maintenance action during the mission.

His acceptance and performance of all the heavy unscheduled maintenance repair actions indicates that the crew recognized his superior technical talent, and that he had confidence in his own ability to perform the necessary work. This was amply demonstrated by his initiative in troubleshooting and diagnosing all of the electrical and electronic failures that occurred. He was able to diagnose a serious breakdown in one piece of scientific electronic gear and to improvise an on-the-spot modification to restore the essential equipment function when no spare was available. Over 40% of all the total recorded mission maintenance was performed by this one crew member.

Crew Member No. 5 was primarily an operations man or pilot. His secondary function was related to monitoring the vessel and its equipment. The greatest portion of his total maintenance effort was related to the vessel's scheduled and unscheduled maintenance (7.9% of total), as distinguished from experiment equipment maintenance. As a point of interest, unscheduled maintenance or repairs were a minor part of his effort, 3.3% of the total maintenance workload.

Crew Member No. 6 was primarily a scientist-engineer, and his secondary function was maintenance of the vessel and its equipment. His maintenance workload involved 15.3% of the scheduled and 31.9% of all the unscheduled maintenance performed during the mission. His responsibility for the NASA scientific experiment occupied a good portion of his time; however, he was able to perform 18% of the total maintenance workload during the mission.

7.2.3 Maintenance Workload Distribution

Figure 7-7 summarizes the maintenance work performed as a percentage of the scheduled, unscheduled, and total maintenance performed by each crew member. Crew

MAINTENANCE WORKLOAD DISTRIBUTION

Crew Member		Scheduled, %	Unscheduled, %	Total, %
No.	Symbol			
1	0	1.6	0	1.4
2	*	33.8	0.9	28.4
3	□	4.5	0.6	3.9
4	△	36.0	64.1	40.4
5	+	8.8	3.3	7.9
6	⧗	15.3	31.9	18.0

Figure 7-7. Maintenance Workload Distribution

members 2, 4, and 6 (the two oceanographers, and the NASA engineer) performed 86.8% of all the maintenance during the mission. These same three men did 84.1% of all the scheduled maintenance, whereas only two of them (crew members 4 and 6) performed 96% of all the unscheduled maintenance.

7.3 MAINTENANCE TASK ANALYSIS

7.3.1 General

This portion of the data analysis deals with the subjective aspects of maintenance performed during this GSDM.

When a maintenance task or action is analyzed, those aspects relating to physical design accessibility, tool requirements, safety, spares and test equipment become quite obvious. There are many things a maintenance man brings to the job such as: skill, experience, training and knowledge of the task, ability to use technical information, and resourcefulness or ability to improvise. All of these factors are, in turn, affected by the working environment.

The maintenance man's efficiency is influenced by environmental factors, such as stress, lighting, tight quarters, temperature, and humidity. His mental attitude also has an effect, especially in the areas of motivation and boredom. All of these factors are inherent in every maintenance action. Admittedly, some are difficult to measure, but their influence can affect the amount of time required to perform any given maintenance task. In the following discussion, an attempt is made to relate these factors to the performance of maintenance aboard the BEN FRANKLIN.

7.3.2 Skills

One of the most significant factors affecting the successful completion of the GSDM was the cross-section of technical skills in the crew. During scheduled maintenance, the workload was generally shared by most of the crew. However, when an unscheduled maintenance task appeared for which there was no special preparation or procedure, this task was always performed by one of two crew members. This fact suggests that these two men were confident enough in their capabilities to assume this burden in order to insure a higher level of mission success. The factors which instill this level of confidence are heavily influenced by the attitude of the individual and his general background of experience.

Figure 7-8 shows various maintenance tasks ranked in order of difficulty and the crew members who performed each task. There is an obvious relationship between technical skill levels observed and the difficulty of the maintenance tasks performed by the various crew members.

As shown in Figure 7-8, Crew Members 4 and 6 were the two individuals who performed all of the difficult tasks and most of the moderate tasks. At the lower end of the difficulty scale, Crew Members 3 and 5 performed the remainder of the maintenance.

The availability of a highly-skilled technician aboard the vessel resulted in successful repairs on electronic equipment without the aid of any technical information (Task 47). This was accomplished by detailed tracing of circuits which required a thorough understanding of the general theory and operation of various types of circuits involved. Another interesting aspect of this skill was demonstrated when a failure in one circuit induced a secondary failure. By rewiring the circuits, switching several functions around, and substituting parts into the original high-priority circuit, the equipment was put back in operation. Motivation was an important factor in accomplishing these tasks; however, skill was also an important ingredient.

7.3.3 Learning and Performance

Another factor of high interest was the effect of learning on the performance of maintenance tasks during the mission.

Those tasks which resulted in a slow learning were generally those in which there were several interrelated steps that involved a high degree of organization, such as setting-up a large number of Agar plates for the Anderson Air Sampler. In this case, repeated performance of this task led to the development of a system which saved time.

In the case where a high level of organization was not required, improvement in the time to perform the task was not noted, indicating a fast level of learning.

A percent learning of over 100% would indicate a situation of negative learning, where each subsequent task in fact took longer than the previous one. This could indicate effects of increasing stress.

MAINTENANCE SKILL ANALYSIS

Task No.	Maintenance Action	Skill Rating	Crew Member
23	Macerator Wiring Repair	High	4 & 6
35	Aux Inverter Failure	High	4 & 6
36	Floor Counter Sys Redesign	High	4 & 6
38	Current Meter Failure	High	4
40	Tape Recorder Bearing Failure	High	4
43	Pulse Meter Failure	High	4
47	Position Depth Recorder Failure	High	4
1	Battery & Hull Resistance Test	Moderate	3 & 5
9	Propulsion System Test	Moderate	3, 5 & 6
10	Bacterial Filter Replacement	Moderate	6
22	Fuse Replacement	Moderate	4, 5 & 6
27	Fathometer Failure	Moderate	4
28	Sub-Bottom Profilter Failure	Moderate	4
29	Magnetometer Failure	Moderate	4
31	Ship Compass Failure	Moderate	4
33	Light Transometer Failure	Moderate	4
32	Sleep Monitor Failure	Moderate	4 & 6
2	Penetrator Inspection	Low	3 & 5
3	Sea Valve Cycling	Low	3 & 5
4	Hydraulic System Inspection	Low	3 & 5
5	Pneumatic System Inspection	Low	3 & 5
17	LiOH Panel Replacement	Low	All

Figure 7-8. Maintenance Skill Analysis (Sheet 1 of 2)

MAINTENANCE SKILL ANALYSIS

Task No.	Maintenance Action	Skill Rating	Crew Member
18	Silica Gel Replacement	Low	All
34	Commode Handle Repair	Low	5
37	Clogged Shower Sink	Low	5
42	Air Regulator Leak	Low	3 & 5
41	Penetrator Leak	Low	3 & 5

Summation

Crew Member	High	Moderate	Low
3	0	2	6
4	7	7	0
5	0	3	8
6	3	4	0

Figure 7-8. Maintenance Skill Analysis (Sheet 2 of 2)

To get a better insight into the effects of learning on repetitive maintenance tasks, the scheduled maintenance data were analyzed. This analysis defined the percent learning curve associated with the performance of each task.

The percent learning associated with each task was defined by the following equation*:

$$\%\ \text{Learning} = \left(1 - \left[\frac{\text{Log}\ \dfrac{T_1}{T_N}}{\text{Log}\ N}\right]\right) \times 100$$

where:

T_1 = First value of repair time

N = Number of times repair is performed

T_N = Cumulative average time over the N repetitions

Figure 7-9 tabulates the results of the analysis for a number of repetitive maintenance tasks. In reviewing these results, learning fell into two basic areas: tasks that were learned fast and those that required more time to develop proficiency.

Those tasks in which fast learning was noted, corresponded with tasks which were very set in procedure and did not require decision making, such as Task 9. This task required that a megger-ohm tester be connected between a terminal point and ground. The value of the resistance was then recorded. The electrical terminals, 24 in all, were located in four junction boxes. It was necessary to gain access to the six terminals in each box by removing the box cover and repeating the procedure for each box. Once the location of the terminals and boxes were known and the megger-ohm test became routine, there was little possibility of improving the maintenance time.

Those tasks which took longer to learn were characterized as tasks in which a high level of proficiency was required, and where unique decisions were made each time they were performed, such as Tasks 13 and 14. For these tasks, selected biological samples

*Reference: PRODUCTION PLANNING AND INVENTORY CONTROL by John F. Magee, Published by McGraw Hill, N.Y., 1958, 1st Edition.

MAINTENANCE ACTION LEARNING DURING THE MISSION

Task No.	Maintenance Action	Learning, %
	Fast Learning	
1	Battery Voltage & Resistance Test	99.0
9	Megger Check	99.3
11	Water System Check	99.3
12	Human Flora Test	99.3
	Slow Learning	
10	Bacterial Filter Replacement	64.8
13 & 14	Environmental Testing	78.4

Figure 7-9. Maintenance Action Learning

were taken from the interior surfaces of the vessel. These samples were then analyzed for a bacterial count. This analysis was unique to each sample; therefore, little learning could be accomplished, except after a great deal of experience.

In Task 10, the replacement of the bacterial filter required exceptional care to prevent contamination, and a system for accomplishing the task had to be developed. This produced a slow-learning cycle.

It is apparent that to effectively use the available manpower for scheduled maintenance aboard a space-type vehicle, step-by-step detailed maintenance procedures must be designed for quick and easy performance, with minimum demands for extensive and complex training.

7.3.4 Training

The training aspect of the experiment had a significant effect on the performance of maintenance during the course of the mission. It was essential to the mission that the crew be thoroughly familiar with the general operation of the vehicle's systems. They also had to be familiar with the specific troubleshooting and repair procedures, prepared as part of the NASA Maintainability Experiment, for selected equipment. This helped to relieve much of the anxiety in performing maintenance and produced crew confidence.

The procedures for scheduled and unscheduled maintenance also added confidence to the crew in that they knew that they did not have to rely on memory to accomplish any of the controlled maintenance tasks.

Because of the limited time available for crew training, specialization in specific maintenance tasks was necessary. This expedient limited the flexibility of individual crew members to perform other maintenance tasks. The results of this approach are presented in Figure 7-8 which illustrates the workload and skill stratification.

7.3.5 Onboard Maintenance Provisioning

Providing the proper technical information, tools, spares, and test equipment is a very important part of the total maintainability task. The ability to support the onboard maintenance function was amply demonstrated by the fact that the crew reported satisfaction with the spares, tools, and technical information supplied for the controlled maintenance tasks.

The only provisioning weakness encountered was in the area of uncontrolled electronic maintenance which was outside the scope of this experiment. The complex electronic equipment, with its many unique and discrete elements, poses problems in identifying all of the necessary spares, tools, and technical information requirements, as well as providing spares that are effective from both a mission success probability and weight viewpoint.

Maintainability analyses were performed on the controlled maintenance tasks. From these data, the level of maintenance and skills available were established. In effect, the spares support was directed towards satisfying equipment complexity and skill levels available for repair. The same approach was also used to define the requirements for technical information, test equipment, and tools used in performing the onboard controlled maintenance.

7.3.6 Working Conditions

The working environment at times can make the performance of a task more difficult. During the GSDM this condition did occur.

The mission data indicated one task in this category. During the dock-side time trials, the times recorded for microbial sampling tasks were somewhat less than the values established during the mission. Considering the amount of space required to set-up these tasks, the numerous pieces of equipment that must be handled, and the interference of these actions with the normal activity in the vessel, it became apparent that the limited amount of space available did impose a penalty on the performance of these tasks. The work area was established in the ward room on the table. The size of the table was quite small when considering the amount of unpacking and handling of Petri dishes which was involved in performing these complex tasks. Since there was no special work area other than this table set aside for performing this work, every piece of equipment had to be broken down and returned to its proper storage area after the sampling was complete.

Similar effects were noted in the repair of electronic equipment. There was no specific maintenance repair area or workshop set up in the vessel. As a consequence, repairs were made on removed equipment in various areas, such as the passageway, the bunks, and the aforementioned table. This did not lead to efficient repair operations.

7.3.7 Repetitive Tasks

One type of maintenance prediction in gross error with actual mission data was the inspection of the vessel systems. In general, a safety inspection was performed every 4 hours during the mission. This inspection included the vessel, penetrators, sea-valves, and the hydraulic and pneumatic systems. Generally speaking, these tasks became tedious since they were repetitive.

As a result, the different inspections were combined by the crew into one operation and in time became quite superficial in nature. This trend could be accounted for in two ways. First, as the performance of a system proved to be dependable, less attention was directed to it by the crew. Secondly, the importance of accomplishing these safety inspections in every detail obviously diminished with the passage of time.

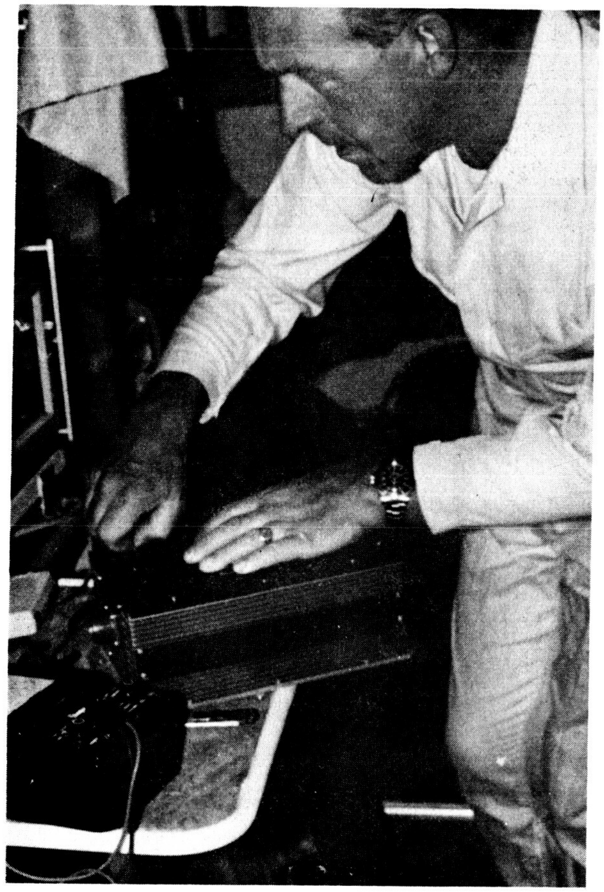
The consequence of these trends was that the safety inspections which normally should take half an hour were condensed to 8 minutes. Better organization or integration of these similar inspection tasks should have been accomplished prior to the mission. This accounted for some of the time differential. An important element inherent in the final reduction of inspection time was the diminishing importance the crew attached to the task details as the mission progressed. Therefore, if there were good reasons for repetitive safety type inspections, then priorities should have been established and the crew indoctrinated with the importance of these details.

7.3.8 Maintenance Levels

Figures 7-10 to 7-13 illustrate the different levels of maintenance performed as a direct analogy to the levels that would be performed aboard a long-duration spacecraft.

The first or system level of maintenance is shown in Figures 7-10 and 7-11. Black box removal is shown in Figure 7-10. On-line system adjustment and system fault isolation by manual probing to determine the faulty module, are shown in Figure 7-11.

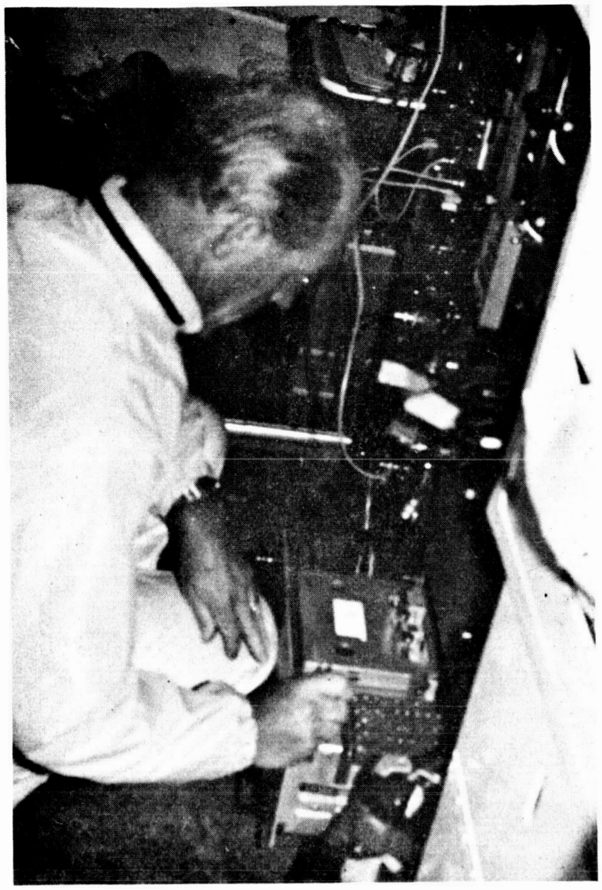
The second or bench level of maintenance is illustrated in Figure 7-12, which shows the faulty printed circuit board being removed and the failed parts (transistors) about to be replaced.



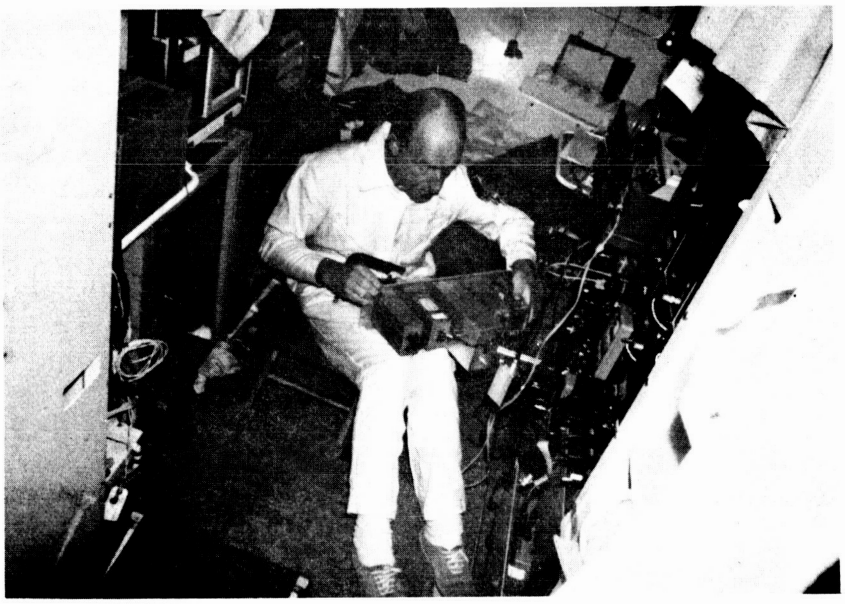
Disassembly

Removal

Figure 7-10. Black Box Removal and Disassembly



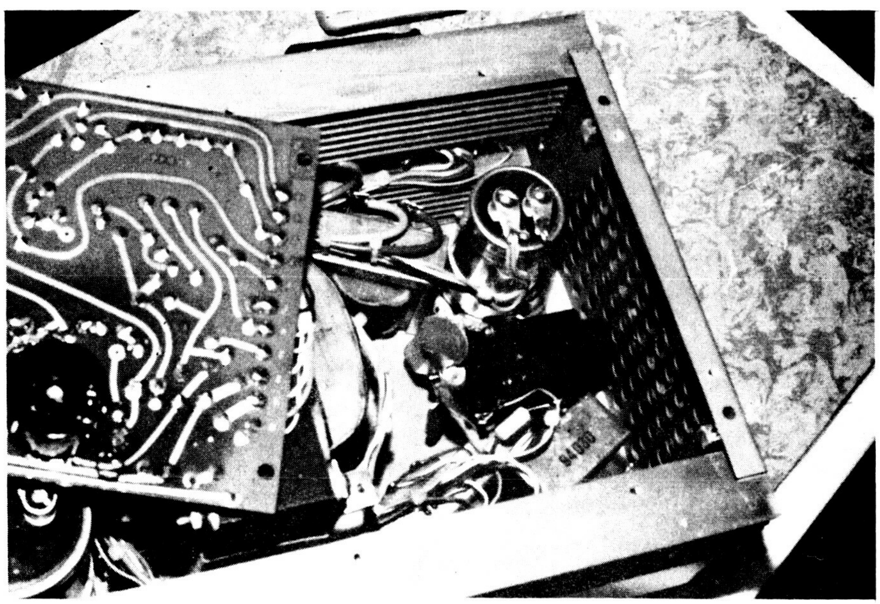
System Adjustment



Fault Isolation

Figure 7-11. System Adjustment and Fault Isolation

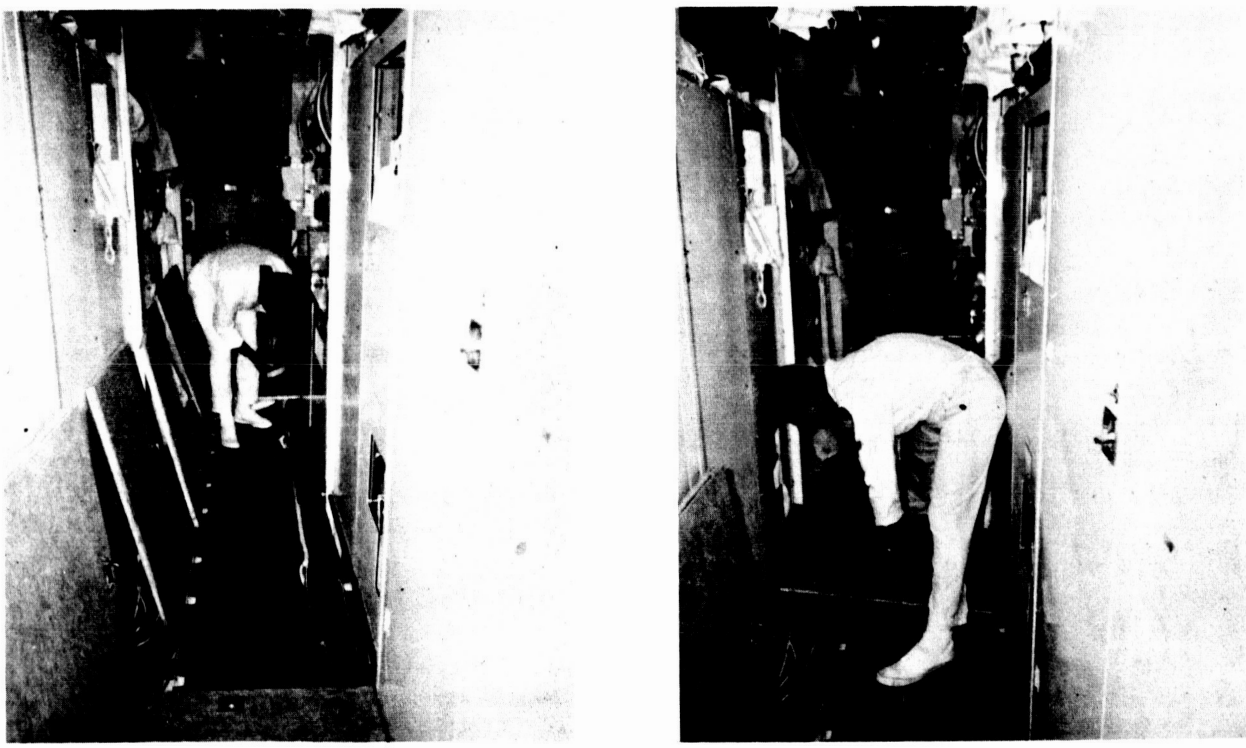
Removal



Replacement

Figure 7-12. Subassembly Removal and Replacement

Visual Inspection



Preparation for Battery - Ground Measurement

Figure 7-13. Scheduled Maintenance

Some of the scheduled maintenance activities included general visual inspections and battery cable resistance measurements shown in Figure 7-13.

7.4 PREDICTION TECHNIQUE EVALUATION

After post-mission general data review, it became apparent that the amount of quantitative data was not sufficient for mathematical analysis and the data were somewhat random in nature. However, the data were adequate for certain conclusions.

The first consideration in the numerical analysis was to identify the correlation between each estimating technique and the actual data. As a result of this correlation, it was then possible to evaluate each technique with respect to qualitative and quantitative accuracy.

Dock-side time trials were compared with the actual mission data to determine the nature of the performance of maintenance in a controlled unstressed environment as compared with that encountered during the GSDM.

After reviewing these data with mathematical experts, the only approach that could be taken to gain a valid insight into its significance was the use of standard statistical procedures, such as regression analysis. By the use of this approach, several analytical tests were applied to these data, giving as complete an evaluation as possible.

In developing the statistical analysis of the mission data, multiple linear regression equations were developed for each set of data:

- Method II (MIL-HDBK-472) predictions as compared with actual GSDM data
- Method III (MIL-HDBK-472) predictions as compared with actual GSDM data
- Dock-side task performance trials as compared with actual GSDM data
- Control case of Method II (Aircraft Program) predictions as compared with early operational data from that aircraft program.

The last method was introduced into this analysis to provide a control, or a gage with which to measure the repeatability of the Method II prediction technique.

7.4.1 Method II Prediction Analysis

The results of the multiple regression analysis for the correlation between Method II estimates and actual mission data are shown in Figures 7-14 and 7-15.

The reduction of Method II predictions shows that estimates were generally conservative for any estimate up to 35 minutes. The slope of the regression line is almost in line with the line of perfect prediction, indicating that little if any correction factor is required

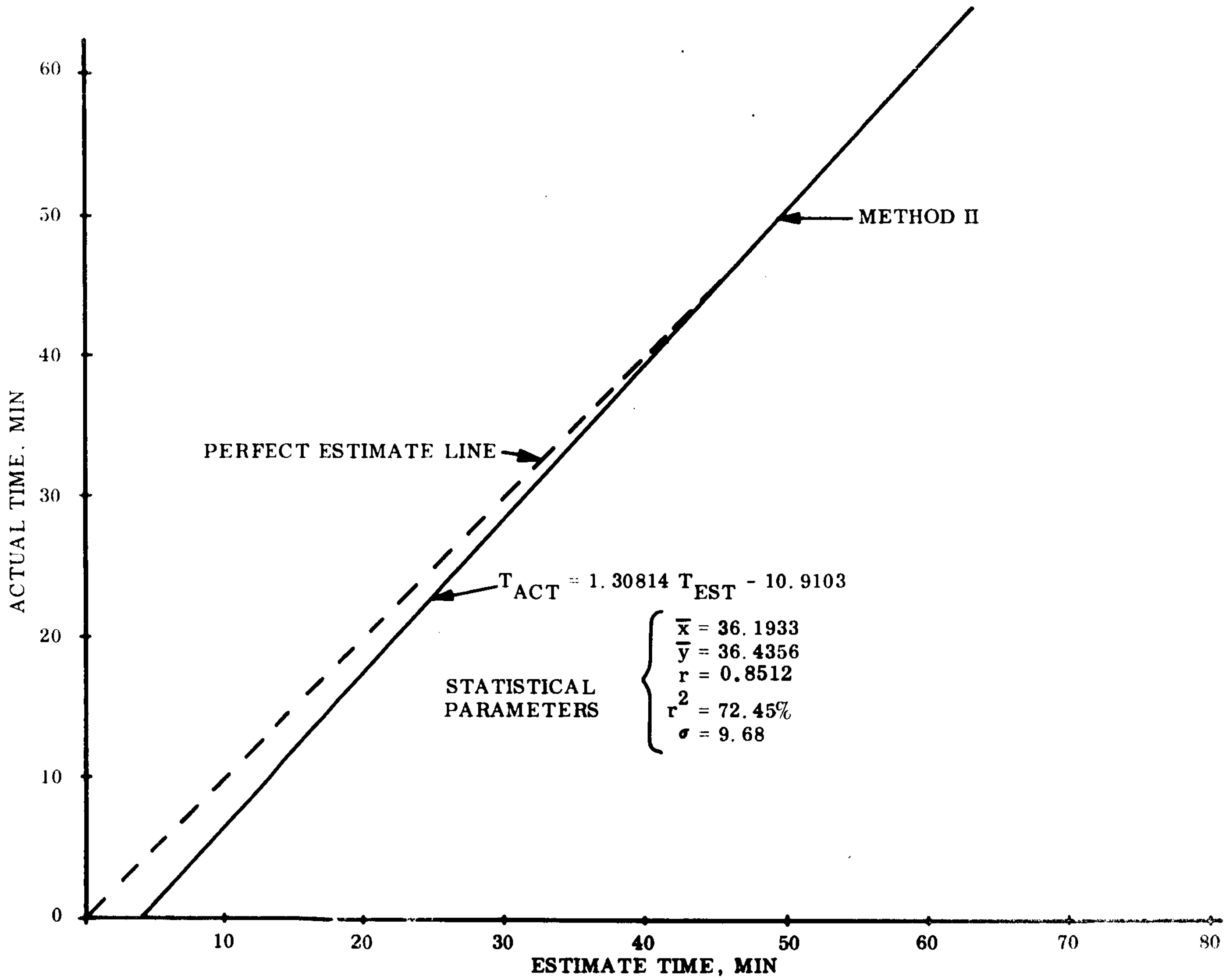


Figure 7-14. Actual vs Method II Task Time

MREG1S

METHØD 2B

VERSIØN ØF 03/15/1968

SUMMARY ØF THE INPUT

VARIABLE	MEAN	VARIANCE	STD. DEV.
ACT.	36.4356	1359.55	36.8721
PREDICT.	36.1933	676.234	26.0045
DØCKSIDE	32.0889	768.484	27.7215

CORRELATIØN MATRIX (INPUT VARIABLES)

	ACT	PREDICT.	DØCKSIDE
ACT.	1.000000	.922581	.971716
PREDICT.	.922581	1.000000	.961918
DØCKSIDE	.971716	.961918	1.000000

ENTER THE NUMBER ØF INDEPENDENT VARIABLES AND THEIR
INDICES ? 1,1

	DEGREES ØF FREEDØM	SUM ØF SQUARES	MEAN SQUARE
TØTAL	8	10876.4	1359.55
REGRESSIØN	1	9257.52	9257.52
REMAINDER	7	1618.89	231.270

VARIABLE	CØEFFICIENT	STANDARD ERRØR	T-STATISTIC
1(1)	1.30814	.206760	6.32685

INDEX ØF DETERMINATIØN .8512
F-RATIØ TEST STATISTIC 40.0291

THE REGRESSIØN EQUATIØN IS Y= 1.30814 X+-10.9103

Figure 7-15. Method II Computer Run

to adjust the estimate to real values. There is a bias in our predictions of about 8.00 minutes which if added to the predicted values would result in realistic estimates of actual times to perform required tasks.

The next consideration was to evaluate the quality of the regression line in Figure 7-14. The value for the standard deviation was 9.68 minutes. This value indicates the "goodness of fit" to be poor, but this error is relative to the population size and would have been smaller with a much larger number of data points. The next parameter was the correlation coefficient r which cannot be greater than +1 or be less than -1. A value of +1 denotes perfect functional relationship between y and x. An increasing x associated with an increasing y, where $r = -1$, would again be a perfect functional relationship, but with x inversely associated with y. When $r = 0$, there is no relationship between x and y.

The Method II correlation coefficient r resulted in a value of 0.85, indicating a high degree of direct correlation between the predicted values and the actual values from the mission.

Another measure of quality in regression analysis is the value of the coefficient of determination (r^2). This parameter expresses the percent of confidence in the data, with ($1 - r^2$) as the percent that can be explained due to accidental randomness in the data points. The value for (r^2) was 72.45% which also indicated that our Method II relationships with actual mission data were not random in nature. The resulting overall assessment of the Method II technique indicated a generally reliable means of predicting overall maintenance task time with some inaccuracies, particularly on items that required short repair times.

7.4.2 Method III Prediction Analysis

The previously described procedure was repeated for the analysis of Method III data; the results of this analysis are shown in Figures 7-16 and 7-17.

The regression line equation showed the existence of a very poor correlation between the predicted value of Method III and the actual data. The mean standard deviation was twice the standard deviation of Method II, and the degree of correlation was correspondingly very low. When Method III was compared with Method II, it was clear that Method II provides a much better tool with which to predict maintenance task times.

7.4.3 Dock-Side Time Trials

This analysis was developed to define the relationship between the dock-side time trials and the GSDM data. The result of this correlation analysis is shown in Figures 7-18 and 7-19. The correlation coefficient for dock-side time trial was not quite as good as

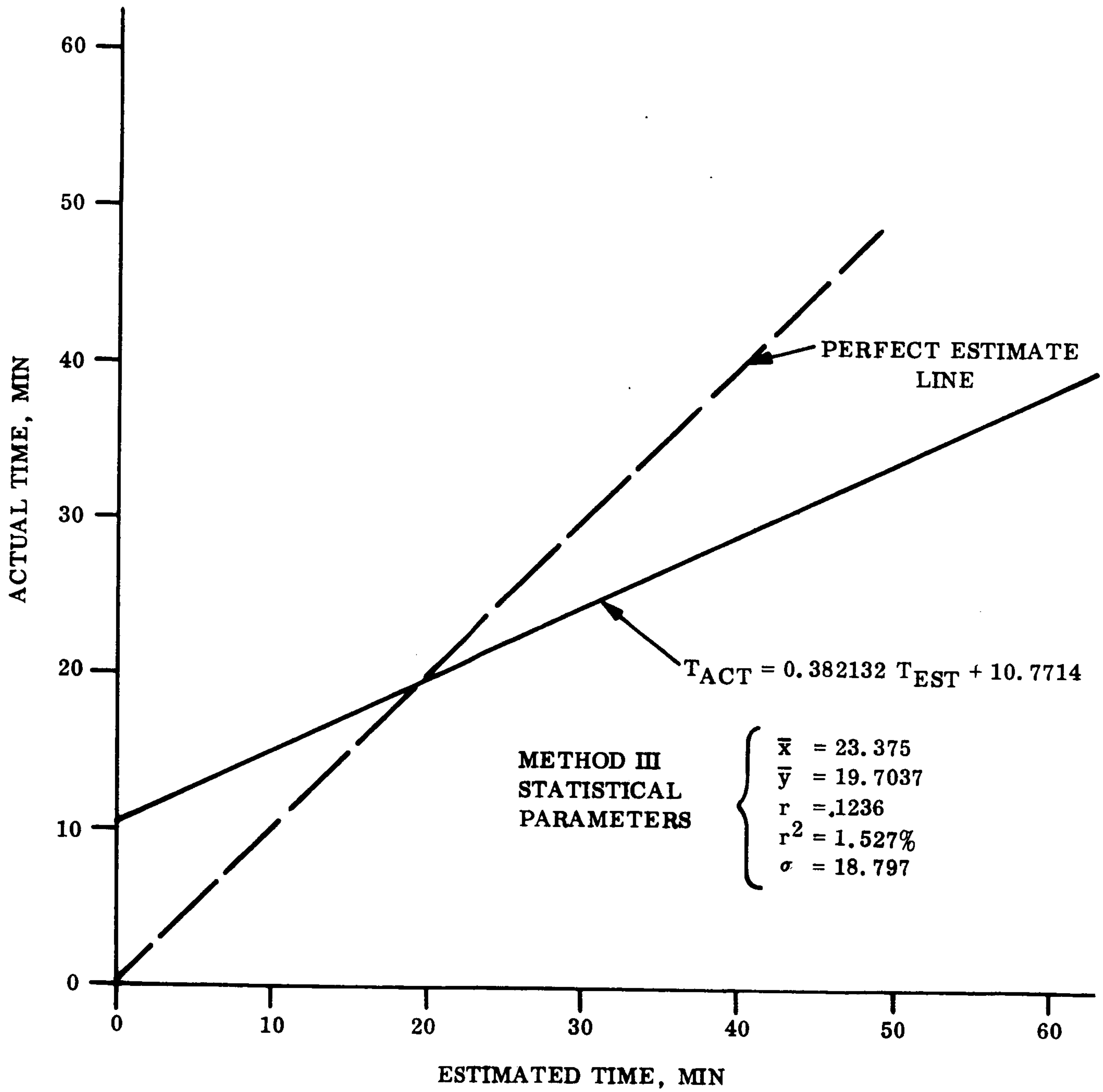


Figure 7-16. Actual vs Method III Task Time

```
MREG1$

METHØD 3

VERSIØN ØF 03/15/1968


                        SUMMARY ØF THE INPUT
VARIABLE                  MEAN        VARIANCE      STD. DEV.
 ACT.                    19.7037       299.629        17.3098
 PREDICT.                23.3750       253.696        15.9279


                      CØRRELATIØN MATRIX (INPUT VARIABLES)
                       Y            X 1
ACT.               1.000000      .351624
PREDICT.           .351624      1.000000


ENTER THE NUMBER ØF INDEPENDENT VARIABLES AND THEIR
INDICES ? 1,1


     .             .  DEGREES   ØF .  SUM ØF SQUARES.     MEAN SQUARE     .
     .             .    FREEDØM    .                .                     .
     . TØTAL       .        7      .        2097.40 .             299.629 .
     . REGRESSIØN.          1      .        259.322 .             259.322 .
     . REMAINDER   .        6      .        1838.08 .             306.347 .


VARIABLE          CØEFFICIENT          STANDARD ERRØR       T-STATISTIC
 1( 1)              .382132               .415337              .920053

INDEX ØF DETERMINATIØN          .1236
F-RATIØ TEST STATISTIC          .8465



THE REGRESSIØN EQUATIØN IS    Y= .382132 X+ 10.7714
```

Figure 7-17. Method III Computer Run

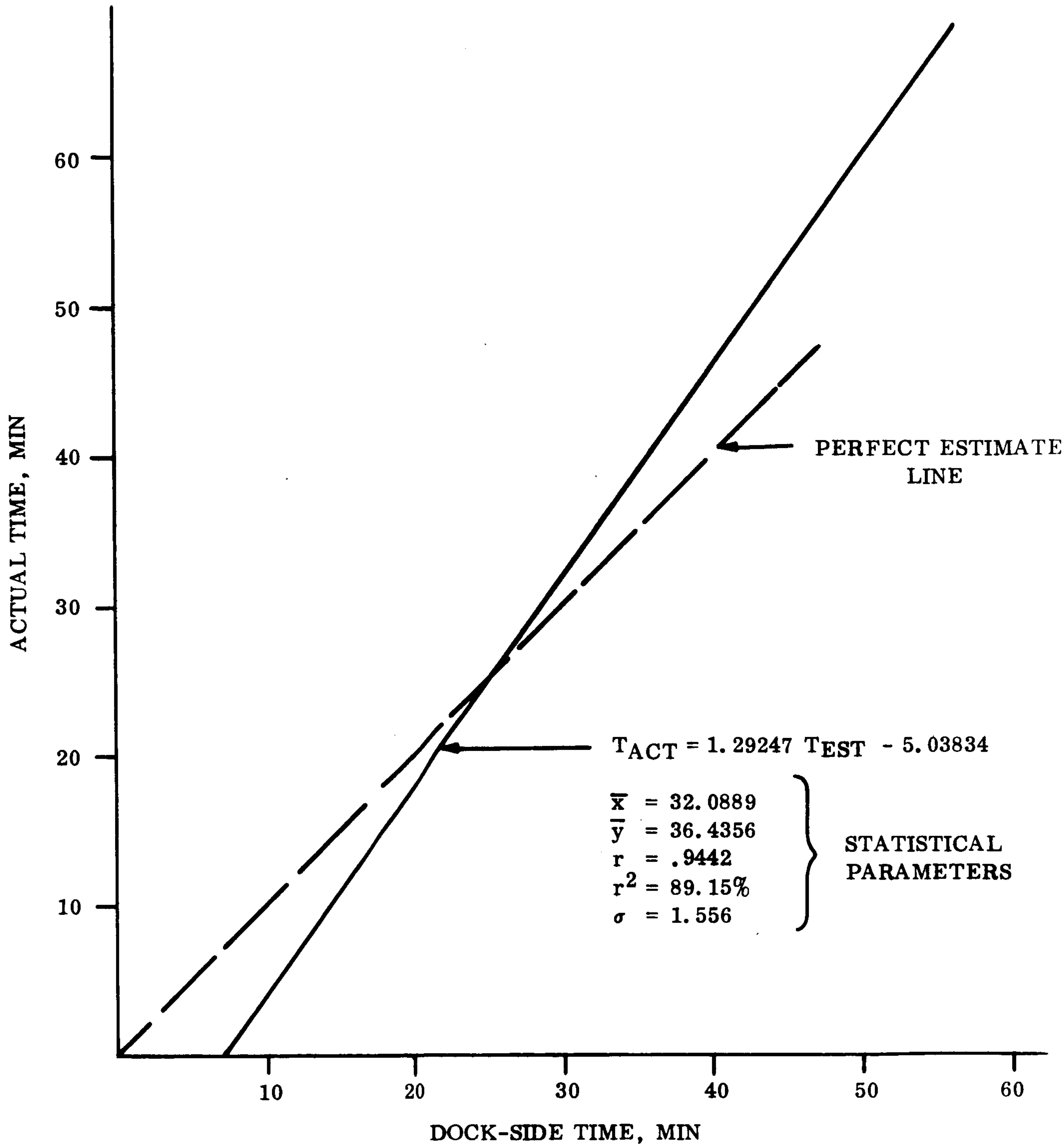


Figure 7-18. Dock-side vs Actual Task Time

```
MREG1$

DØCKSIDE TRIALS

VERSIØN ØF 03/15/1963


                      SUMMARY ØF THE INPUT
VARIABLE                 MEAN         VARIANCE       STD. DEV.
ACT.                    36.4356        1359.55        36.8721
PREDICT                 36.1933        676.234        26.0045
DØCKSIDE                32.0889        768.484        27.7215


                   CØRRELATIØN MATRIX (INPUT VARIABLES)
               ACT.         PREDICT.   DØCKSIDE
 ACT.          1.000000     .922581    .971716
PREDICT        .922581     1.000000    .961918
DØCKSIDE       .971716      .961918   1.000000


ENTER THE NUMBER ØF INDEPENDENT VARIABLES AND THEIR
INDICES ? 1,2

    .             .  DEGREES  ØF .  SUM ØF SQUARES.    MEAN SQUARE      .
    .             .   FREEDØM    .                .                     .
    . TØTAL       .      8       .       10876.4  .          1359.55    .
    . REGRESSIØN.        1       .       10269.9  .          10269.9    .
    . REMAINDER .        7       .       606.555  .          86.6507    .


VARIABLE          CØEFFICIENT        STANDARD ERRØR       T-STATISTIC
 1( 2)             1.29247              .118720              10.8867


INDEX ØF DETERMINATIØN        .9442
F-RATIØ TEST STATISTIC     118.5203




THE REGRESSIØN EQUATIØN IS    Y= 1.29247 X+-5.03834
```

Figure 7-19. Dock-Side Computer Run

Method II, r = 0.85 as compared to r = 0.94, but the standard deviation value (σ) for dock-side trial was much smaller than Method II predictions. This indicated that the actual task times were relatively close to the dock-side time trials.

The dock-side time trials were intended to act as a control in the evaluation of stress during the GSDM. Due to a particularly heavy workload in the few days before the mission, the dock-side time trials were not completely successful in obtaining accurate time trials with actual crew members performing all of the tasks. However, sufficient data were developed to obtain some insight into certain aspects of maintenance. Some general conclusions drawn from the regression analysis indicated a relationship between the average dock-side task time and mission task time.

Generally speaking, for all tasks requiring less than 25 minutes, there seemed to be a learning effect which demonstrated itself in shorter actual task times.

In the case of those tasks which required maintenance times greater than 25 minutes, there were complications which were introduced during the course of the mission. These complications tended to increase the amount of time required to perform these tasks under mission conditions. It was a fact that those tasks which required more than half an hour were generally very involved or complex maintenance actions (most of them were scheduled maintenance procedures).

It can also be concluded that some aspects of the crew confinement added complications to the performance of these tasks. Some of these factors were: stress, lack of complete proficiency in performing certain difficult tasks, lack of adequate spare parts and equipment, and, finally, a desire not to create a disturbance while the rest of the crew was sleeping. This experiment was not geared to detect these sensitive causal factors.

There was no clear cut indication that the stresses had any discernible effect on the performance of various maintenance actions. This does not mean that there was no delta for stressed versus unstressed environments, but rather that there were no serious or critical equipment failures that required maintenance under adverse conditions. An extension of the mission may have brought such conditions into focus.

7.4.4 Method II Prediction Comparisons

The Method II predictions were found to be best in predicting the actual maintenance task times. To determine whether the results of this mission were truly representative of Method II prediction technique, a control was established. This control consisted of a correlation analysis of early maintenance data for a modern aircraft program and Method II predictions for the same aircraft program. A comparison of the correlation analysis of the BEN FRANKLIN Method II predictions and the correlation analysis of this aircraft program predictions were made (Figures 7-19 and 7-20). The result of this comparison revealed that the slopes of the two regression equations were almost identical, indicating very close agreement between the two programs.

These data are shown in Figure 7-21. The y intercepts of each curve highlight the differences between the two programs. In the case of the aircraft program, the regression equation y intercept indicated that the predictions generally underestimated the maintenance task times. This might be expected from this early feedback data where technicians are cautiously performing maintenance actions on new equipment.

```
MREG1$

A6FILE
VERSIØN ØF 03/15/1968

                    SUMMARY ØF THE INPUT
VARIABLE              MEAN        VARIANCE       STD. DEV.
ACT.                1.98706       2.45688         1.56745
PREDICT.            1.78471       1.87590         1.36964

                  CØRRELATIØN MATRIX (INPUT VARIABLES)
                ACT.      PREDICT.
ACT.          1.000000    .953960
PREDICT       .953960    1.000000


ENTER THE NUMBER OF INDEPENDENT VARIABLES AND THEIR
INDICES ? 1,1
WHAT?
1,1

     .             .  DEGREES   OF .  SUM OF SQUARES.    MEAN SQUARE     .
     .             .    FREEDOM    .                .                    .
     . TOTAL       .      16       .       39.3102  .          2.45688   .
     . REGRESSION.         1       .       35.7738  .          35.7738   .
     . REMAINDER .        15       .       3.53632  .          .235755   .


VARIABLE          COEFFICIENT       STANDARD ERROR       T-STATISTIC
 1( 1)             1.09174          886268E-01             12.3184

INDEX OF DETERMINATION        .91
F-RATIØ TEST STATISTIC     151.74


THE REGRESSIØN EQUATIØN IS    Y= 1.09174 X+ 3.86207E-02
```

Figure 7-20. Aircraft Program Computer Run

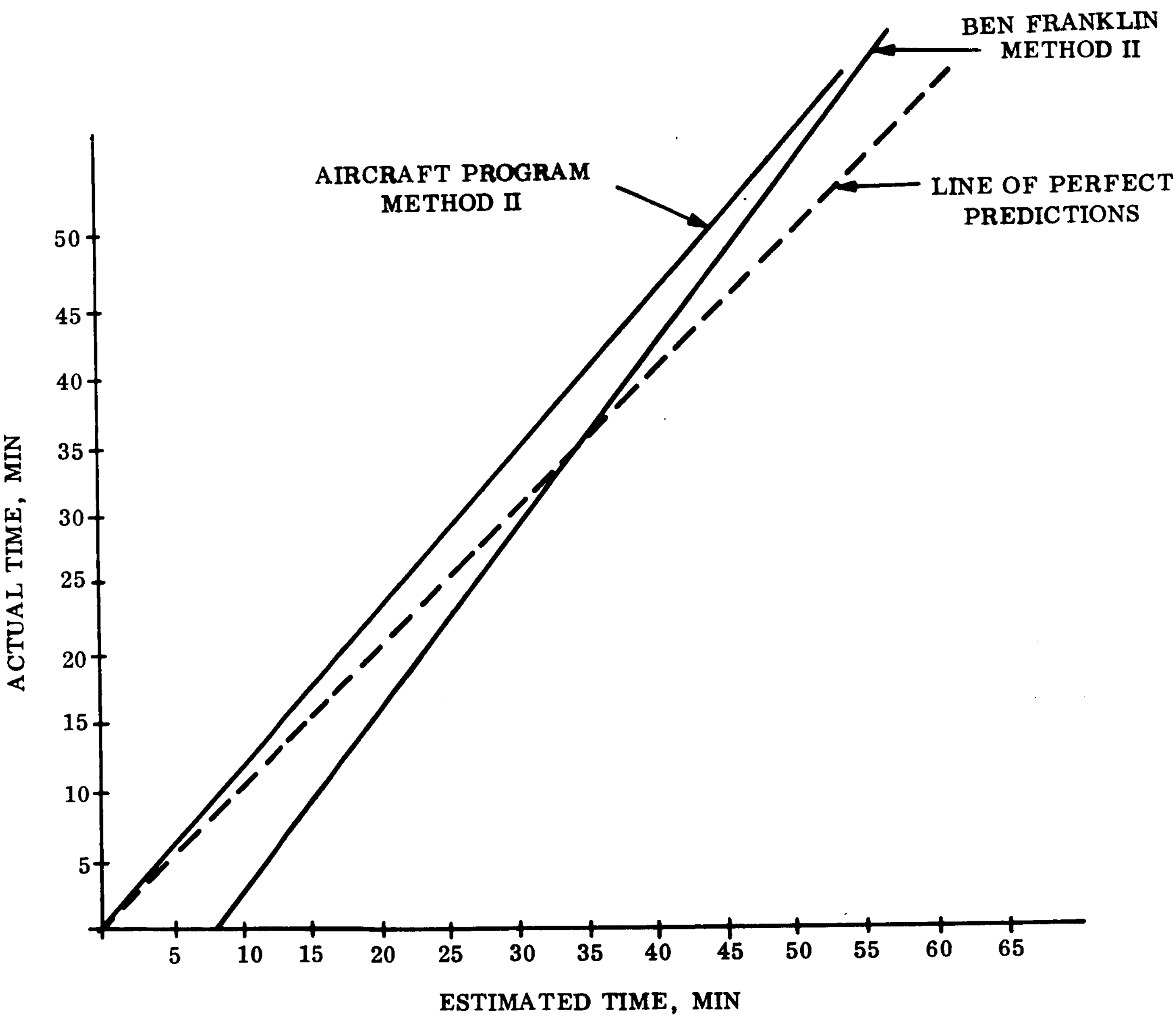


Figure 7-21. Comparison of Prediction Characteristics

SECTION 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The BEN FRANKLIN provided an opportunity to investigate onboard vehicle maintenance under actual mission conditions. The opportunity to study maintenance actions of a complex system in a dynamic situation under total isolation is quite rare. The Gulf Stream Drift Mission (GSDM) with its scientific objectives provided a sense of motivation which placed maintenance into proper perspective with relation to the operation of the entire vehicle. The unique set of conditions associated with the GSDM was a close correlation to a long-duration space-type mission.

The NASA Maintainability Experiment had a rather significant effect on the outcome of the mission. By implementing the various phases of the experiment prior to launch, a number of maintenance problem areas were uncovered and appropriate solutions implemented. The experiment also redirected the project's thinking concerning spares, tools, training, and the need for onboard technical information. The program did have certain limitations which hampered the execution of the experiment. The experiment was conducted on a non-interference basis with the basic program goals of the GSDM. The experiment was further restricted due to the limited amount of time available before the mission; however, all of the experiment objectives were either achieved or answered in part by the data returned from the mission.

The value of a dynamic test bed as an effective and early evaluator of spacecraft maintainability concepts has been verified by the results obtained from this experiment.

The amount of maintenance performed accounted for 17.3% of the total manpower available during the mission. This means that for a vessel of this complexity, approximately 1/6 of the crew's available time must be planned for maintenance activity. Of this maintenance workload, 74% was devoted to scheduled maintenance. The remaining 26% of the maintenance manpower was devoted to the critical unscheduled maintenance tasks upon which mission success depended. It was noted that during the mission almost all of the unscheduled maintenance was performed by two crew members skilled and experienced in the maintenance field. The skills and experience necessary to repair complex equipment must be present in the make-up of individuals selected for such a mission. It was apparent that training can aid in reducing the problem, but cannot altogether eliminate the need for maintenance skills.

In making an accurate assessment of the anticipated maintenance workload during a space mission, prediction techniques (such as MIL-HBK-472 Method II, etc.) provide a suitable means by which these assessments can be made. The results of this mission indicate that onboard maintenance can be predicted with reasonable accuracy, but that further refinement through additional testing would permit more accurate assessment of individual tasks.

In summary, the significant conclusions resulting from the maintainability experiment were:

- Method II Maintainability Prediction Technique was the best approach for determining mission maintenance requirements
- A dynamic test bed provided valuable maintenance workload and performance data that can be used to define crew requirements for future missions in sealed isolated vehicles
- Maintainability support was essential to mission success
- There was no discernible difference in maintenance times performed under the range of mission stress conditions, compared to pre-mission values
- The crew was resourceful in distributing the maintenance workload to suit varying mission conditions

- A maintenance corner or workshop area with a bench would have improved the efficiency and performance of certain off-line equipment repairs and complex scheduled maintenance testing operations
- Measurement and control of bacteria is a tedious and difficult job.

8.2 RECOMMENDATIONS

There are a number of problems that must be solved if we are to provide the reliable and maintainable equipment necessary for long-duration space missions. The NASA Maintainability Experiment identified and provided preliminary answers to some of these problems.

The BEN FRANKLIN provides a dynamic test bed in a closed environment that can develop, refine, and evaluate new design concepts and techniques related to onboard maintenance of a long-duration spacecraft. The onboard maintenance capability is at least reasonably representative of that required for a space vehicle; therefore, the vessel could be profitably employed as a laboratory to test and develop critical space equipment, such as a maintainable EC/LSS system. It can also provide many answers to the specific problems of how to plan for and obtain an efficient, integrated, onboard repair and maintenance capability.

There are many areas of investigation into space maintainability which could be pursued during further missions of this vessel, such as:

- Development and checkout of on-line test and fault isolation criteria
- Investigation of the sensitivity of skill levels on the ability to perform maintenance functions
- Development of techniques for the storage and retrieval of technical information required for onboard maintenance

- Development of specific maintenance skill levels and experience requirements for crew members on long-duration space missions
- Development and refinement of maintainability design techniques which will reduce the requirements for spares, skills, tools, and repair times associated with both scheduled and unscheduled maintenance
- Development and investigation of the optimum levels of maintenance for space equipment so that mission reliability requirements can be achieved with minimum impact on critical parameters of performance, cost, weight, and volume
- Development of the facilities required for off-line repair of space equipment (work area, tools, test equipment, BIT, technical information, and spares)
- Refinement of the maintainability prediction techniques, especially Methods II, III, and IV of MIL-HDBK-472
- Development of an efficient maintenance reporting system for documentation of problems and experience as a feedback to design.

These recommendations for further investigation of space maintainability problems obviously are related to the configuration of the BEN FRANKLIN. Some of these future studies can be conducted with the vessel in its present configuration, while other more rewarding studies, such as the evaluation of space type EC/LSS, would require reconfiguration of the vessel.

It would be possible to schedule these studies in a logical sequence for a series of missions, gradually expanding the capabilities of the vessel to suit a development program.

Evaluation of actual prototype space hardware could be done at far less cost and much earlier than an orbiting vehicle could do the job. It might be argued that the same evaluation and development testing could take place in a laboratory or test chamber. However, a chamber test program with man in a closed loop would be the same magnitude in cost, but without the influence of the dynamic environment obtained aboard a vehicle on a scientific mission. This dynamic test ingredient is essential to the proper evaluation of functional performance and onboard maintenance capability of new equipment.

8.3 GUIDELINES FOR FUTURE MAINTAINABILITY EXPERIMENTS

In performing any follow-on maintainability experiments aboard the BEN FRANKLIN, certain areas could be improved, such as:

- Use of a better and more efficient reporting system for maintenance actions that will permit recording more detail with less of a burden to the crew, such as pre-printed check-off forms and voice tape recorders
- Establishment of a better set of baseline data through the dock-side time trials from which it will be possible to determine the deviations due to the stressed environment. Each maintenance action should be repeated with various individuals to establish a more valid baseline.
- An expansion of the controlled maintenance tasks to provide more data points for a rigorous mathematical analysis and verification of the prediction techniques
- A greater emphasis on the preparation and predictions for unscheduled maintenance since this will be the area of greatest concern to space operations. Failure mode and effect analysis should be performed for all onboard systems and equipment to define the unscheduled maintenance tasks that must be covered.
- The selection of a crew representative of the skills needed for long-duration space operations, especially in the area of onboard maintenance capability for all of the systems and equipment installed.

In addition, if a follow-on mission includes modifications, then the BEN FRANKLIN could become an ideal space simulator through:

- Modification of existing equipment to permit the kind of maintenance action at all levels (i. e., system, black box, subassembly) that will be encountered during long-duration space missions
- Installation of new space-type equipment, such as a maintainable environmental control/life support system for evaluation and development prior to committing such equipment to an expensive space shot.

APPENDIX A

SPACE MAINTAINABILITY BACKGROUND

As man travels into space for longer and longer periods of time, there is a critical need to develop and augment the existing technologies so as to allow him to exist safely in a hostile environment. The space industry is beginning to recognize that complex space vehicles will require onboard maintainability if they are to have a high probability of success for long-duration missions.

Recent experience has demonstrated that onboard maintainability may be necessary even on relatively short missions. Vehicle designs incorporating provisions for such maintainability, if not traded-off carefully, may impose severe weight penalties on these short missions. On long missions, however, studies* have shown that there is a crossover point (Figure A-1) where manned maintenance will be more weight effective than high reliability achieved with maximum redundancy. The crossover point for a typically complex space vehicle occurs when the mission exceeds several months. A probability of mission success goal of 0.95, or better, can be achieved if we build in the capability of restoring malfunctioning equipment to an "all-up" status (Figure A-2) before crew and vehicle performance becomes impaired. Without this capability, mission success probabilities for complex vehicles have been projected as approaching an unsatisfactory 0.20 after 2 years.

To achieve the desired maintainability in any given vehicle requires that we provide a maintainable design with the spares and tools, accessibility, skills, training, and technical

- - - - -

*AIAA 67-984: System Effectiveness Through Interchangeability. Frumkin, B., AIAA 4th Annual Meeting and Technical Display, Anaheim, Calif., Oct. 23/27, 1967.

II.1.1: Redundancy vs Maintainability - Some Conclusions on the Crossover For Manned Mission. 2nd National Conference on Space Maintenance and Extra-Vehicular Activities, Sponsored by the USAF Aero Propulsion Laboratory and NASA, Las Vegas, Nev., Aug. 6/8, 1968.

information necessary to do the job. If we do not design carefully and comprehensively for the correct degree of maintainability, we could end up with a vehicle that consists solely of spare parts and equipment manned by a crew occupied only with keeping this complex vehicle operational. There would be no room or time available for experiments and useful space work; the reason why we are in space in the first place.

The required onboard maintenance capability does not happen spontaneously. It must be carefully developed and planned for from the initial concepts through the specific designs of the vehicle, systems, subsystems, subassemblies, components, and parts. This is the engineering discipline or technology known as "Maintainability".

The key then is to develop the maintainability techniques and concepts that will be "mission effective." This demands that onboard maintenance be accomplished with:

- Minimum consumption of onboard resources, such as manhours, fuel, spares, power, etc.
- Minimum impact on functional performance (downtime and degradation)
- Minimum impact on mission weight and cost.

The ability to predict and provide for effective onboard maintenance capability in space must be refined prior to committing men, machines, and resources to an expensive and hazardous space shot.

Due to lack of actual experience and accurate information on the performance of maintenance in a space environment, an urgent need has arisen to obtain such information prior to actual long-term missions. Since it is not possible to properly simulate all of the conditions which constitute a true space environment on Earth, we must select special test environments to include as many of these space conditions as possible to perform our maintainability experiments and obtain valid data.

In the quest to find a suitable simulation of space environment, many trade-offs must be made. These trade-offs are intended to find the most economical and feasible means of gaining the required information while retaining the highest degree of fidelity and confidence in the results.

All of the factors which affect space maintenance have some analogy to earth-bound maintenance performed on aircraft, for example. There are many aspects to predicting the repair of complex systems in a difficult environment which need clarification. We must gain an insight into the effects of an isolated, stressed, and sealed environment on man's ability to perform complex maintenance actions. Some techniques lend themselves quite readily to valid simulation for early evaluation of specific maintenance parameters, while others require higher degrees of fidelity to obtain meaningful information. The search for a simulator to provide this high degree of fidelity involves consideration of environmental test chambers, zero-gravity mechanisms, aircraft, and ocean vehicles.

The ideal test installation should have a sealed environment, zero gravity, and the stress of a hazardous mission where the crew has meaningful technical duties to perform. So far, only one installation offered a majority of these ideal test conditions: The BEN FRANKLIN deep submersible on its month-long drift mission.

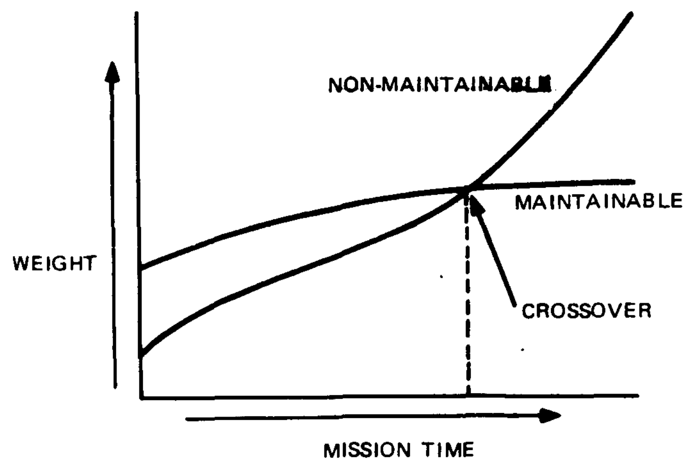


Figure A-1. Crossover of Maintainable vs Non-Maintainable System Weights with Respect to Time

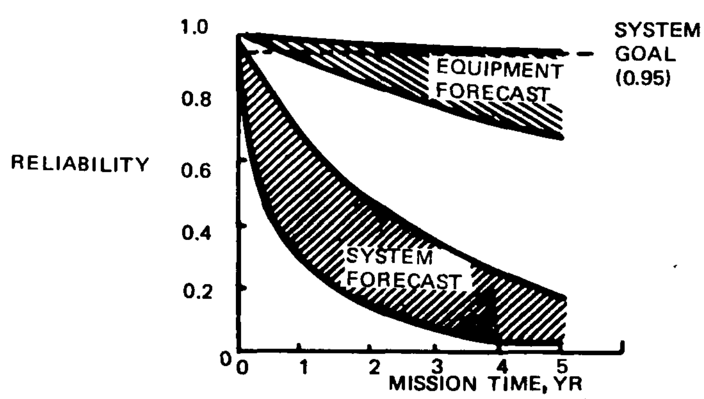


Figure A-2. Reliability Objective/Forecast

APPENDIX B

DRIFT MISSION PLANNING

A. PROGRAM PLAN

Phase I - Definition of Work Scope for the Experiment

Phase I had as its goal the definition of the exact scope of the work to be covered by the experiment.

The submersible is a relatively large and complex vehicle and it was not physically possible to perform detailed maintainability analysis, write troubleshooting procedures, make check lists, forms, and estimates for every piece of onboard gear in the 3 months prior to departure.

The Maintainability Engineers on this project reviewed all of the systems and equipment on the vehicle to determine the most promising candidates for the experiment. Ideal systems, such as the external TV cameras, were eliminated since they could not be serviced or repaired. Each system was examined for:

- Scheduled maintenance requirements
- Unscheduled maintenance requirements
- Availability of detailed design information
- Similarity to space type of equipment
- Accessibility to the crew.

Twenty-seven individual and significant "controlled" maintenance tasks were finally selected as the core of the experiment. (Refer to Paragraph D for task description.) These tasks covered both types of maintenance and included work on equipment, such as power monitoring, attitude control, communications, propulsion, bacteria monitoring and control, etc. It was felt that concentration on these specific tasks would yield better results than a "shotgun" approach.

Phase II - Documentation of the Controlled Maintenance Tasks

During this phase, the equipment affected by the selected (controlled) maintenance actions was analyzed in detail to provide all of the scheduled maintenance requirements, as well as the major failure modes most likely to be encountered during the 30-day mission. This involved review of all available equipment drawings, schematics, manuals, and handbooks, as well as contact with vendors, installation engineers, crew members, and equipment, both on and off the vehicle. The following was accomplished during this phase:

- A detailed maintenance procedure was written for each of the selected tasks
- Special charts were generated to show fuse box locations
- Short, concise check lists were generated for the scheduled maintenance inspection type tasks
- Compact calculation sheets were generated for tasks, such as power consumption, drive motor lead hull resistance, and battery lead hull resistance
- Data sheets were generated to record essential performance and maintenance data.

Phase III - Cognizant Engineer Review of Controlled Maintenance Tasks

All cognizant Project Engineers responsible for equipment covered by the controlled maintenance tasks reviewed the procedure, check lists, and data sheets with maintainability engineering to arrive at a mutually agreeable, technically accurate write-up.

Phase IV - Project Management Review of Experiment

Project Management, including the Project Engineer, Program Manager, Operations Manager, and Captain of the BEN FRANKLIN reviewed the total content of the NASA Maintainability Experiment. Final corrections were then made.

Phase V - Maintainability Analysis and Predictions

A maintainability analysis with predictions of MTTR was completed for each maintenance procedure in the experiment. As a result of the analysis, recommendations were made for spares, tools, and test equipment to support the affected systems during the mission. Predictions were made using both Methods II and III of MIL-HDBK-472 for each task.

Phase VI - Assembly of NASA Maintainability Experiment Workbook

A NASA Maintainability Workbook was assembled to include the 27 maintenance procedures, plus all check lists, charts, and data sheets for recording the elapsed time of all maintenance actions. Special formats were provided to permit incremental task element recording for easier comparison of results with Method II and III predictions.

Phase VII - Drift Mission Crew Review and Familiarization

The entire six-man BEN FRANKLIN crew was given the opportunity to review and comment on the content of the NASA Maintainability Experiment. In particular the NASA Engineer, the BEN FRANKLIN Captain, and the Pilot were given a special briefing and familiarization with the content and details of the maintenance procedures, check lists, charts, data sheets, spares, and tools for the experiment.

Phase VIII - Dock-Side Time Trials

Dock-side time trials and demonstrations were performed on the vehicle by crew members and other qualified personnel to establish baseline data, and to be certain that all maintenance procedures were fully understood. All scheduled maintenance tasks were exercised except for those parts requiring disassembly of equipment. Similarly, all of the unscheduled maintenance repair tasks had to be checked by simulation exercises.

Phase IX - Mission Performance Data Recording

This phase covered all of the data taking and recording of maintenance action accomplished by the crew during the 30-day mission.

Phase X - Crew Debriefing, Data Reduction, and Analysis

Maintainability Engineering participated in the full crew debriefing sessions held at Grumman, Bethpage, directly after the mission. This permitted questioning of the crew to ascertain additional details, rationale, and background information in connection with various maintenance actions as recorded in log books and data sheets. Following this, data reduction and analysis of all the feedback data was accomplished to:

- Ascertain correlation with predictions
- Determine trends, learning curves, and stress condition effects
- Determine effectivity of mission preparations
- Ascertain validity of correlations and trends via application of known analysis techniques
- Determine maintenance workload assumed by each crew member
- Determine total maintenance workload performed by the entire crew.

Phase XI - Preparation of Final Report

Final report on the NASA Maintainability Experiment was prepared by Maintainability Engineering.

B. MAINTAINABILITY EXPERIMENT PLAN

The onboard maintenance actions during the mission were expected to fall into the following categories:

(1) Controlled Maintenance Tasks

(a) Scheduled - All of the planned scheduled maintenance tasks including inspections which were to occur on the equipment selected and analyzed for the experiment.

(b) Unscheduled - All of the selected unscheduled maintenance repair actions which were indicated by the analysis as possible candidate repairs to the equipment covered by the experiment.

(2) Uncontrolled Maintenance Tasks

(a) Scheduled - All of the scheduled maintenance tasks to be performed on equipment not covered by the experiment, such as the government furnished oceanographic equipment.

(b) Unscheduled - All of the unscheduled maintenance repair actions which occur on equipment not covered by the experiment.

A firm ground rule was established for the experiment in that all maintenance actions, whether controlled or uncontrolled, would be recorded for later analysis. This was intended to provide an indication of the total maintenance workload during the mission. The NASA Maintenance Engineer was equipped with a stop watch and a full set of maintenance record data sheets for quick entry of individual maintenance action elapsed times.

As a result of the maintainability analysis performed on the equipment covered by the 27 maintenance procedures, certain spare parts, tools, test equipment, and other necessary equipment were recommended and carried aboard. This was not only intended to complete the experiment, but also to enhance the probability of mission success. Figure B-1 presents a block diagram indicating the development and flow of the NASA Maintainability Experiment. This diagram covers all aspects from the initial system analysis to the final evaluation.

C. EQUIPMENT AND MAINTENANCE TASKS COVERED BY THE EXPERIMENT

There were a total of 13 scheduled maintenance tasks and 14 unscheduled maintenance repairs included as the controlled portion of the NASA Maintainability Experiment on the GSDM. (Refer to Appendix C for actual procedures.)

Five scheduled inspection tasks were chosen since these tasks were essential to the safety and operation of the vessel:

- S-2 Hull Penetrator Inspection
- S-3 Sea Valve Inspection and Operational Check
- S-4 Hydraulic System Inspection
- S-5 Pneumatic System Inspection
- S-6 Fathometer Inspection and Service.

Three scheduled maintenance tasks involved testing and monitoring for degradation and failure in the critical power and propulsion systems:

- S-1 Battery Voltage Monitoring and Hull Resistance Check
- S-7 Ampere-Hour System Check for Power Consumption

- S-10 Hull Resistance Check of Main Propulsion and Rotational Motors.

Of these three, the ampere-hour system maintenance procedure contained system calibration and repair instructions, plus an alternate power saving mode of operation.

The NASA tape recorder inspection and service task S-9 was added since it typified a fairly simple routine job.

The remainder of the scheduled maintenance tasks involved work in what is considered to be one of the more critical areas for long-duration space missions - bacteria and microbial contamination control:

- S-11 Bacteria Filter Element Replacement (water system)
- S-12 Water System Potability Test
- S-13 Microbial Contamination Tests for Interior Air, Surfaces, and Personnel

It was anticipated that learning curve effects would be observed from repetitive observations of routine type scheduled maintenance actions.

The 14 unscheduled maintenance tasks were selected as a representative sample of emergency repairs involving power distribution, communication, oxygen supply, mechanical, electrical, experiment, and sterilization equipment. Some of these repairs were designed to prevent degradation and malfunction of equipment, while others were necessary to prevent catastrophic consequences and possible mission abort. The 14 tasks were titled as follows:

- U-1 Fuse Troubleshooting and Replacement
- U-2 Underwater Telephone Repair
- U-3 Macerator Repair
- U-4 Water Pump Repair
- U-5 Gas Chromatograph
- U-6 Camera Service and Repair
- U-7 Foreman Experiment Service and Repair

- U-8 Egan Experiment Repair
- U-9 Crew Performance Tester Repair
- U-10 Oxygen Regulator Repair
- U-11 Battery Cell String Jumping
- U-12 Hydraulic and Pneumatic Valve Repair
- U-13 Odor Removal Blower Repair
- U-14 Cold Water Sterilization.

The uncontrolled maintenance tasks, both scheduled and unscheduled, were considered to be a measure of the resourcefulness of the crew since there was to be no formal pre-mission analysis or write-up for these tasks. This does not imply that no thought was given to the service and repair of the equipment outside the NASA Experiment. Both the oceanographic specialists and the submersible specialists in the crew provided their own spares, tools, and technical information. Space was limited, however; therefore, the spare parts, tools, and technical information taken aboard was limited to a selected list based on experience and functional priority or criticality of the affected equipment.

D. MAINTENANCE TASK DESCRIPTION

The controlled maintenance actions were essentially routine maintenance and inspections performed at regular time intervals.

Item S-1 - Battery Monitoring and Resistance to Hull Measurements

The purpose of this task was to inspect and ascertain the general condition of the Power System and batteries at regular intervals during the course of the mission. The batteries were monitored as follows:

- 1st week - every 24 hours
- 2nd week - every 12 hours
- 3rd week - every 6 hours
- 4th week - every 6 hours

The Power System cables were to be checked for resistance above hull (ground) every 60 hours. The status of the batteries was determined by testing for the resistance of each battery string to the hull through voltage readings for each battery string. This maintenance action is essentially a fault isolation and detection routine for unscheduled maintenance task U-11, Battery Cell String Jumping.

The nature of the information resulting from this procedure was vital in determining whether the primary power source was in good condition, and if not, how much degradation had already occurred in the power system. The hull-to-battery string resistance gave an indication as to whether the batteries and the penetrators were being affected by salt water. The voltage value of each string was information required to compute absolute hull resistance.

Item S-2 - Hull Penetrator Inspection

Located along the centerline overhead and in the bilge are hull penetrators which allow all service to pass through the hull. The penetrators provide a water-tight seal against the high external sea-water pressures while submerged. All electrical power, signal, hydraulic, pneumatic, and ballasting system lines are routed through these hull penetrators.

Due to the critical nature of these penetrators the integrity of the fittings must be under constant surveillance for mission safety. This inspection was scheduled every 4 hours. In the event a leak was detected, corrective action (tightening) or mission abort would have been considered.

Item S-3 - Sea Valve Cycling and Inspection

All hydraulic and pneumatic ballast system lines which penetrate the hull are protected by a rotary-action shut-off sea valve. These valves provide a means of isolating all exterior failures from the interior pressure vessel of the BEN FRANKLIN. Due to the position of these sea valves in the various systems, pressure differentials develop that must be relieved by exercising the valves. Also, in the ballast system which is exposed to sea water, there was a potential for sea life to grow on the valve elements with time and thereby cause potential jams when the valves were finally moved.

The critical nature of the sea valves was such that any sort of failure in these units could cause a serious condition. As a result, a 4-hour inspection and valve exercise cycle was established.

Item S-4 - Hydraulic System Inspection

The hydraulic system provides the power to actuate two systems: the shot ballast release system, and the SAS release system. The shot ballast doors are opened when an emergency indicates that the vessel must surface, at which time hydraulic pressure is released from the two door cylinders, allowing the doors to open and release all of the shot ballast. The SAS is a system for releasing samples from the vessel to the surface in small plastic pressure tight balls.

The daily inspection and servicing of the hydraulic system involves: checking all lines and valves for leaks, replenishing hydraulic fluid, and an inspection to insure that the pressure of the shot ballast system is at the proper level. If pressure is low, a pump is used to raise the pressure to the correct valve. Low fluid level would require replenishment.

Item S-5 - Pneumatic System Inspection

The pneumatic system provides the source of high-pressure air required to power the ballast system. This maintenance task provides for regular daily inspections of the pneumatic system. The task was a visual inspection of gages and detection of audible sounds of leaks. If an air leak is suspected, a second procedure is included to permit fault isolation of the leak.

Item S-6 - Fathometer Inspection and Service

The Fathometer provides the necessary information to determine the height of the vessel above the ocean floor. It consists of an echo sounder and a recorder with paper roll chart output of soundings visually showing the contour of the ocean bottom. During the bottom drift portion of the mission, this equipment was very important to the safety of the vessel. This maintenance procedure provided instructions for replacement of the paper roll chart, adjustment of recording pen, replacement of fuses, cleaning, adjusting motor speed, and belt drive replacement. The inspection for condition was scheduled every third day of the mission.

Item S-7 - Battery Consumption Check

The consumption of electrical power was of prime concern throughout the drift mission. To effectively monitor the consumption of power, a special system was designed to monitor the current rate of consumption, and to indicate the total power consumption to date. This maintenance procedure provided a check list for daily recording of data and details for checking the calibration of the system, as well as procedures for troubleshooting and repair of system components.

Item S-8 - Amphere-Hour Battery Consumption (By Voltage)

NOTE: This procedure was deleted due to unsatisfactory correlation of data.

Item S-9 - Service and Inspection of the Tape Recorders

The tape recorder was used as a verbal source of GSDM data. To insure proper servicing and maintenance of this unit, a detailed procedure was provided. The procedure established the steps to be taken to replace tape cassettes, checking and replacement of batteries, and cleaning of tape heads.

Item S-10 - Resistance Check of Propulsion and Rotational Motors

The electrical power leads which connect the battery power to the propulsion system, were of prime concern. Any sea water infiltration into these power cables would result in an extremely dangerous condition should power be applied through the cables. A maintenance procedure was established defining the steps to be taken twice weekly and whenever the power was to be applied to the propulsion system after a period of inactivity. The procedure required that a megger-ohm test to ground (hull) be performed on all 24 power leads connected to the propulsion system motors.

Item S-11 - Cold Water Bacterial Filter Replacement

The protection of the water system outlets was augmented by the use of an ultra-fine microbial filter in each faucet line. These filters were to be replaced every 8 to 10 days regularly, as a precautionary measure, and whenever positive cultures were obtained. This procedure defines the steps to be taken to insure a contamination free replacement of these delicate filter elements.

Item S-12 - Water System Potability Check

The bacteria-free quality of the cold water supply system was an ever present concern. To determine if the water was potable, a detailed sampling and test procedure was written. This sampling and test procedure was scheduled for a daily inspection of the galley sink outlet, and for an inspection of the head sink and shower outlets every 3 days during the mission. These inspections involved taking water samples and developing culture plates, as well as chemical iodine tests.

Item S-13 - Microbial Contamination Check

In a closed environment, such as the BEN FRANKLIN, the balance of microbial flora can change with mission duration; therefore, a detailed interior surface and air sampling procedure was provided. This inspection procedure was scheduled for completion every third day so as to monitor the growth and types of bacteria present. It also involved the taking of human flora samples and the culturing of all samples to permit growth and detection of bacteria colonies.

The unscheduled maintenance procedures covered the repair of those equipments which were considered most likely to fail, and were considered repairable with the limited resources available to the crew during the mission. Each procedure was designed so as to provide a troubleshooting procedure which described the most probable modes of failure. For each mode of failure, a repair procedure was provided. In those situations where repair was not considered feasible, alternate modes of operation were recommended or emergency steps described.

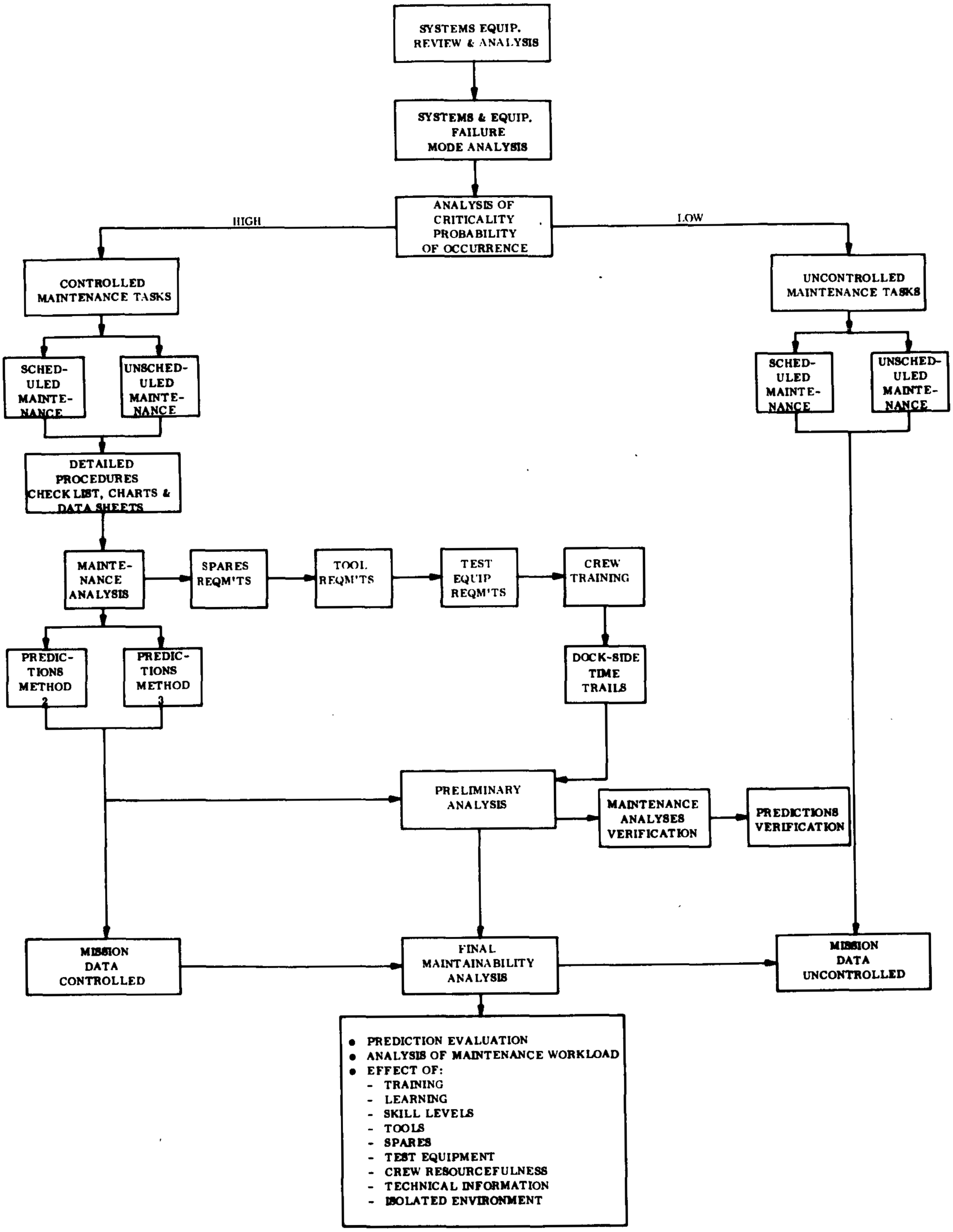


Figure B-1. NASA Maintainability Experiment Block Diagram

APPENDIX "C"

MAINTENANCE PROCEDURES

Two typical maintenance procedures written for this mission are included. Scheduled Maintenance Task S-1 covered battery monitoring and resistance to hull measurements. Following this procedure are the data sheets for recording voltage readings and a calculation sheet to help determine the hull resistance of the cables for detection of abnormalities and trends. The Procedure S-11 covers the replacement of bacteria filters in the cold water system.

SCHEDULED MAINTENANCE PROCEDURE TASK #S-1

BATTERY MONITORING AND RESISTANCE TO HULL MEASUREMENTS

1.0 SCOPE

The battery monitoring test will be performed on all strings of batteries on the Ben Franklin on a scheduled basis.

2.0 PURPOSE

The purpose of this procedure shall be to determine the status of the batteries and/or a trend of the resistance between the battery strings and the boat's hull.

3.0 TEST EQUIPMENT REQUIRED

One (1) AEG and one (1) pit fuse puller
Battery String Voltage & Resistance Data Sheets (5)

4.0 PROCEDURE

1. Record on Data Sheet DVM zero, by putting Sw. "C" to off and DVM polarity Sw. to (+) and then (-).
2. Secure all Power:
   a. Position mode switch to "O" position.
   b. Position B1 batteries switch to "off" position.
   c. Position emergency switch to "emer" position.
   d. Secure amper-hr. system. Turn sw. to "off" position.
   e. Position KB sw. (batt. group volt. sel) to "D" position.

3. Remove floor panels over fuse boxes MFB1 - MFB 4 located on floor between frames 5-9. Order panels for identical replacement.

4. Remove main fuses with fuse puller (shawmut 250A & AEG 160A) which are marked in red on the fuse terminal from main fuse boxes MFB-1-4. These are fuses: E2, E4, E8, E10, E 18, E 29, E 31 and E 33.

5. Turn on 50 VA inverter for the digital volt meter (DVM) by turning sw. "D" to "on".

6. Record to the nearest hundredth all string voltages noting sw. A, B, C, DVM polarity, and DVM/SEL toggle positions indicated on the data sheets. Scan the + 28V strings (B1-1, B1-2, B1-3, B1-4, C1, C2, C3, C4, D1, D2, and D3) with sw. B.
Then scan through all + 56V strings (A1-1, A1-2, A1-3, A2-1, A2-2, A2-3, B2-1, B2-2) with sw. A.

7. Record to the nearest hundredth all string ground voltages on the supplied data sheets, noting sw. positions on data sheet. Scan in order the + 28V + 56V, -28V, and -56V strings, recording 11 & 11, 8 & 8 readings respectively. Order is shown on data sheets.

8. Turn off 50 VA inverter for DVM (sw.D).

9. Replace main fuses with fuse puller in the same manner as extracted by procedure #3.

10. Replace the four (4) floor panels exactly as removed.

11. Reposition mode, B1 batteries. Emergency, KB & A-H switches to their original positions.

COMPUTATIONS:

Compute the equivalent resistance to hull using the equation for each string:

$$R_t = R_c \left[\frac{E}{|V_P| + |V_N|} - 1 \right] \qquad \text{where}$$

R_t = The equivalent resistance of all paths between string & hull.
E = The measured battery string voltage.
V_N = The ground (hull) voltage of the negative sides of ea. string.
V_P = The ground (hull) voltage of the positive sides of ea. string.
R_c = Value of calibrated resistor across DVM terminals.

Digital Voltmeter Operational Procedure

Zero Adjustment--After warmup and before measurements are made, check the instrument zeroing by shorting or disconnecting the input terminals, with red RANGE set to 1 kV and MODE set to NORMAL. Using the front-panel screwdriver adjustment, zero the readout with INPUT set to +. Now set INPUT to -. If the instrument reads off zero, adjust the ZERO EQUALIZER control on the rear of the instrument. Set this to split the difference in zeroing between + and - settings of the INPUT switch and re-zero with ZERO ADJ. This may have to be performed several times to achieve the best (±0.2 digit) zeroing agreement between + and - INPUT settings

DC Voltage Measurement--Set the red RANGE switch to 1 kV, and the MODE switch to NORMAL. Connect the input (red) and signal ground (black) terminals to the dc source being measured. With the HOLD switch in READ position, reduce the red RANGE setting until three digits (with 2.5% overrange to four) are indicated. The OFF-RANGE indicator will be on until the instrument has balanced itself. This is the NORMAL mode of operation of the Model 353. To utilize the full accuracy and resolution of the instrument, place it in the EXPAND mode by dialing in the most significant (leftmost) digit as read from the NORMAL mode indication. (A red 1 in NORMAL is dialed in as a 10). The Model 353 will now indicate four or five digits with 0.25% overranging. Accuracy will be as specified in 1.3.

If the input to the instrument becomes greater than the range selected in either mode, the display will run up to its stop and the OFF-RANGE lamp will remain on. In NORMAL mode, correct by switching to a higher range.

In EXPAND, first try dialing in large first-digits. If this fails, return to NORMAL mode and find the correct range again. The instrument will not be damaged if left in an overloaded state since the circuits are inherently self-limiting. An input of the wrong polarity will cause the OFF-RANGE lamp to turn on and the display will return down past zero to about 997. In EXPAND mode this is accompanied by the indication of two red numbers to the left of the counter. Correct by changing the INPUT switch polarity to start again in NORMAL mode.

In EXPAND mode, an input less than the digit dialed in will also result in double red indication. Reduce the EXPAND setting, or return to NORMAL to correct for this.

NOTE: Never use a reading when the off-range lamp is on, or when the hold switch is retaining an earlier indication.

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

S-1

D

DATA SHEET - BATTERY STRING VOLTAGE READINGS

STRING	FUSE	DVM/SEL TOGGLE	DVM POLARITY	SWITCH A	SWITCH B	SWITCH C	VOLTAGE READINGS (E) TAKEN BY DATE AND HOUR							
B1-1	E13 & 38	VOLTS	+	A1-1	B1-1	+28								
B1-2	E14 & 37				B1-2									
B1-3	E15 & 36				B1-3									
B1-4	E16 & 35				B1-4									
C1	E21 & 22				C-1									
C2	E23 & 24				C-2									
C3	E25 & 26				C-3									
C4	E27 & 28				C-4									
D1	E29 & 30				D-1									
D2	E31 & 32				D-2									
D3	E33 & 34				D-3									
A1-1	E1 & 2	VOLTS	+	A1-1	OFF	+56								
A1-2	E3 & 4			A1-2										
A1-3	E5 & 6			A1-3										
A2-1	E7 & 8			A2-1										
A2-2	E9 & 10			A2-2										
A2-3	E11 & 12			A2-3										
B2-1	E17 & 18			B2-1										
B2-2	E19 & 20			B2-2										

FORM G 315 5 63 (ENG 9)

TABULATION FORM

Figure C-1. Data Sheet - Battery String Voltage Readings

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

DATA SHEET - BATTERY STRING GROUND READINGS

S-1 ②

STRING	FUSE	DVM/SEL TOGGLE	DVM POLARITY	SWITCH A	SWITCH B	SWITCH C	VOLTAGE READINGS TO GROUND BY DATE AND ...								
B1-1	E38	GROUND	+	A1-1	B1-1	+29V									
B1-2	E14			A1-1	B1-2										
B1-3	E36			A1-1	B1-3										
B1-4	E16			A1-1	B1-4										
C1	E22			A1-1	C1										
C2	E24			A1-1	C2										V_N
C3	E26			A1-1	C3										
C4	E28			A1-1	C4										
D1	E30			A1-1	D1										
D2	E32			A1-1	D2										
D3	E33			A1-1	D3										
A1-1	E2			A1-1	D3	+56V									
A1-2	E4			A1-2	D3										
A1-3	E6			A1-2	D3										
A2-1	E8			A2-1	D3										
A2-2	E10			A2-2	D3										
A2-3	E12			A2-3	D3										
B2-1	E18			B2-1	D3										
B2-2	E20			B2-2	D3										
D3	E33		−	B2-2	D3	-28V									
D2	E31			B2-2	D2										
D1	E29			B2-2	D1										
C4	E27			B2-2	C4										V_P
C3	E25			B2-2	C3										
C2	E23			B2-2	C2										
C1	E21			B2-2	C1										
B1-4	E35			B2-2	B1-4										
B1-3	E15			B2-2	B1-3										
B1-2	E37			B2-2	B1-2										
B1-1	E13			B2-2	B1-1										
B2-2	E19			B2-2	OFF	-56V									
B2-1	E17			B2-1											
A2-3	E11			A2-3											
A2-2	E9			A2-2											
A2-1	E7			A2-1											
A1-3	E5			A1-3											
A1-2	E3			A1-2											
A1-1	E1			A1-1											

Figure C-2. Data Sheet - Battery String Ground Readings

DATA SHEET - BATTERY STRING TO HULL RESISTANCE CALCULATION

S-1

CELL STRING	NOMINAL VOLTAGE	A E	B V_N	C V_P	D $V_P + \lvert V_N \rvert$	E $\frac{E}{V_P + \lvert V_N \rvert}$	F $\frac{E}{V_P + \lvert V_N \rvert} - 1$	G $50{,}000 / \left(\frac{E}{V_P + \lvert V_N \rvert} - 1\right)$	CALCULATED RESISTANCE (G)
B1-1 B1-2 B1-3 B1-4	28V DC								
C1 C2 C3 C4									
D1 D2 D3	28V DC								
A1-1 A1-2 A1-3	56V DC								
A2-1 A2-2 A2-3									
B2-1 B2-2	56V DC								

DATE:
TIME:
OBSERVER:

PAGE 8

Figure C-3. Data Sheet - Battery String Hull Resistance Calculations

SCHEDULED MAINTENANCE PROCEDURE TASK #S-11

Cold Water Bacteria Filter Replacement

1.0 SCOPE

This document provides a procedure for the replacement of the Pall cold water system bacteria filters on a scheduled basis.

2.0 PURPOSE

To provide a standard, simplified procedure for the replacement of this essential element in the potable cold water system.

3.0 TOOLS AND EQUIPMENT REQUIRED

3 ea. Pall Bacterial Filters # ACY-4463URA BHK element sealed factory sterlized bags.

1 ea. Plastic bucket

4.0 PROCEDURE

Each of the three Pall Bacteria Filters installed downstream of the three water system pumps must have a filter element change every 8-10 days maximum. Filter change must also be accomplished when required by the results of the culture tests.

(1) Change all three of the following filters when required: galley sink pump, shower pump, and head sink pump.

(2) Shut off the cold water tank supply valves.

(3) Locate each filter assembly in turn on the downstream side of and near it's water pump and replace the element as follows:

(4) Grasp the filter housing with hands and unscrew in counter clockwise direction. Catch any residual water in bucket. Carefully stow the housing to prevent contamination of inner walls.

(5) Pull out the dirty filter element from the filter body and place in bucket.

(6) Carefully open the new filter element bag so as to expose the end that goes into the filter body but do not touch it with the hands or permit it to touch any other areas of clothing, walls, floor,

etc., or it will be contaminated. If it becomes contaminated, do not install it. Get another unit.

(7) Grasp the element using the bag as a glove and insert firmly into the filter body until it seats and is retained.

(8) Pull off the plastic bag and immediately reinstall the filter element housing. Screw on firmly, by hand, in a clockwise direction.

(9) Place dirty filter element in the bag and dispose in garbage disposal.

(10) After all 3 filter elements are changed, turn on required tank supply valve (s) and leak check each filter with pump on for a few seconds.

5.0 Estimated consumption of filter elements is as follows:

Max time of 42 days x 3 filters $\div$ 8 days =
$\frac{126}{8} \approx 16$ filter elements.

Applying maintenance derate for human errors of 20% for installation such as this adds 4 more. Estimated changes in 42 days for unscheduled bacterial requirements adds 25% more for a maximum estimated total of 25 elements for a 42 day mission.

APPENDIX D
MAINTAINABILITY ANALYSIS AND PREDICTION TECHNIQUES

A condensed outline of the four procedures from MIL-HDBK-472 are described in the following paragraphs.

PROCEDURE I

This procedure is used to predict system downtime of airborne electronic and electromechanical systems involving modular replacement at the flight-line. The procedure relies on "Elemental Activity" as the fundamental element of downtime from which other measures of downtime are developed through a process of synthesis of time distributions.

The Elemental Activity is a simple maintenance action of short duration and relatively small variance which does not vary appreciably from one system to another.

The ultimate measure of maintainability in this technique is the distribution of System Downtimes. Intermediate measures include the distribution of times for the various Elemental Activities, Maintenance Categories, Malfunction Active Repair Time, Malfunction Repair Time, System Repair Time, and System Downtime.

In the original development of the prediction procedure, data were employed from malfunction repairs on the AN/ASB-4 Bombing and Navigation System (used in the B-52 Bomber). In testing and refining the prediction system, data were used from seven other systems:

AN/APN-89	AN/APX-25
AN/ARC-34	AN/ARN-21
AN/ARC-65	MD-1
AN/AIC-10	

PROCEDURE II

This maintainability prediction procedure describes the methods and techniques which are used to predict Corrective, Preventive, and Active Maintenance parameters.

Active Maintenance time consists of two basic components, namely, Corrective and Preventive Maintenance time. Corrective Maintenance is the maintenance performed to restore an item to a satisfactory condition by providing correction of a malfunction which has caused degradation of the item below the specified performance. Preventive Maintenance is the maintenance performed to retain an item in satisfactory operation condition by providing systematic inspection, detection, and prevention of incipient failures. Preventive Maintenance can be either scheduled or unscheduled, depending upon the requirements of the mission.

Active Maintenance Prediction assesses the average man-hours of work to perform the required corrective and preventive maintenance tasks.

As applied in this procedure, Corrective Maintenance time includes only actual repair time which is the period when repair work is in progress. Therefore, it excludes such parameters of measure as "administrative time" or "logistic time", etc., which are usually considered in the definition of Corrective Maintenance. There are two methods which are presented for predicting Corrective Maintenance. The first method, described in Part A of this procedure, results in a maintainability prediction expressed in hours because it utilizes tabulated maintenance task repair times, recorded in hours, which have been established from past experience. The second method, explained in Part B of this procedure, does not use tabulated task times. Instead it utilized estimates of man-hours required to perform a maintenance task which are based on past experience or an analysis of the design with respect to maintenance.

The two different measures, one in terms of hours which is representative of actual elapsed time, and the other in man-hours which is a measure of manpower required to complete a maintenance activity in a given time, have of necessity resulted in the development of a different symbology for each method. However, once the repair times have been established either in hours or man-hours, the actual prediction procedures for both Parts A and B are similar in that the techniques and work sheets are almost identical.

The two most important parameters in the field of Maintainability are the duration of downtime due to maintenance, and the number and types of personnel required to perform the maintenance. Each are important measures of maintainability and ideally, both should be kept at a minimum. On certain critical missions, however, the number of maintenance man-hours required may not be as important as minimizing the time required to repair regardless of the other factors involved. Conversely, when downtime is not of paramount significance, the number of man-hours becomes an important parameter to measure and control to reduce operating costs. This procedure outlines the methods of predicting both parametersoof measure, the results of which can be utilized for design improvement or other evaluations.

In any case, a fundamental philosophy is that the magnitude of the repair time, for a discrete repair, is the sum of the individual maintenance task times which are required for its completion. Seven such maintenance task elements are assumed to effect the magnitude of maintenance time: Localization, Isolation, Disassembly, Interchange, Reassembly, Alignment, and Check Out. The equipment design is analyzed for these elements and an estimate is made of the elapsed time for each element. The sum of the elemental times then becomes the Mean Time to Restore or Repair (MTTR). The number and types of men required to perform the entire task (all seven elements) times the elapsed time for each element provides the estimated Maintenance Man-Hours (MMH) and skills necessary to do the job.

PROCEDURE III

This maintainability procedure describes a method of performing a maintainability prediction of ground electronic systems and equipment by utilizing the basic principles of random sampling and by quantifying all of the qualitative factors inherent in a maintenance action.

The underlying philosophy of this procedure is that system failures are principally due to the malfunction of replaceable items; therefore, the time cycle for the various steps required to replace these items is a measure of downtime which is a parameter of system maintainability. The duration of this downtime is assumed to be a function of specific design parameters which relate to: the physical configuration of the system; the facilities provided for maintenance by the design; and the degree of maintenance skills required of personnel charged with the repair responsibility.

The procedure also assumes that because of a basic uniformity of design, a random selection of replaceable items by class will provide a representative sample of maintenance tasks whose time of performance can be established by simulation in a manner representative of system characteristics in actual operation.

The assignment of the times of performance for each of the steps involved in the maintenance cycle, commonly referred to as maintenance tasks, is determined by using three types of check lists. These are intended to provide a uniform method of scoring the various maintenance tasks and are labeled Check Lists A, B, and C, respectively. Check List A is used for scoring physical design factors, Check List B scores design dictates/facilities, and Check List C is used to score design dictates/maintenance skills. The theory is employed that by using these check lists, which include uniform scoring and scoring criteria, variations due to individual appraisers are minimized and the resulting scores can then be correlated with actual downtime. A regression equation is provided for this purpose which provides a corresponding estimate of downtime when the numerical A, B, and C scores are substituted therein. The solution of this equation results in an estimate of downtime.

The correlation between predicted and observed values can be good, provided that adequate information is available and mature experienced analysts are used.

The data utilized for the development of this prediction procedure were obtained during the surveillance of three equipments of varying complexity, use, maintenance, and packaging concepts, as well as assessing the nature of their circuitry. The three equipments were:

(a) AN/FPS-2: Long-Range Search Radar, two channels. Average complexity, has 10,976 parts. Maintenance performed at the "part level."

(b) AN/FST-2: Two-Channel Data Processor which converts analog radar returns to digital form. Average complexity, has 114,500 parts. Maintenance is performed at the "module level."

(c) AN/GKA-5: Time-Division Data Link Transmitting Equipment. Contains both digital and radio frequency sections. Average complexity, has 44,520 parts. The digital section uses boards, and maintenance is provided by "modular replacement", that is replacing the defective boards at the "board level." The RF section consists of individual parts, and maintenance is performed by replacing defective parts.

PROCEDURE IV

This procedure is based on the use of historical experience, subjective evaluation, expert judgment, and selective measurement for predicting the downtime of a system/equipment. The procedure uses existing data to the extent available. It provides an orderly process by which the prediction can be made and integrates preventive and corrective maintenance. Task times to perform various maintenance actions are estimated and then combined to predict overall system/equipment maintainability.

This procedure recognizes that throughout a mission a system/equipment performs various operational functions and that the maintenance time depends upon the specific operational function which is in process. An operational function is defined as that particular function which the system is performing at the specific interval of time during which the maintainability analysis is being conducted. In other words, the procedure requires the development of a mission/maintenance profile which specifies the various operational functions of the system and the scheduled preventive maintenance actions required for each operational function.

A series of mission/maintenance profiles must be established based on the system operational requirements. These profiles shall specify the schedules of operational functions and preventive maintenance actions for a given calendar time. The mean corrective downtime and preventive downtime for the system are calculated in sequence by function, mission/maintenance profile, and complete system.

APPENDIX E

EXPERIMENT MAINTENANCE

REPORT FORM AND INSTRUCTIONS

Grumman

MAINTENANCE REPORT
BEN FRANKLIN

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

BETHPAGE, LONG ISLAND, NEW YORK 11714

This document for
collection of data
in compliance with
requirement of
Contract No. NAS 8-30172

MISSION START DATE

____

INTRODUCTION

The Maintenance Report Form is the means through which all data relating to the Maintainability portion of the NASA study will be documented. The information to be recorded on this document are of two types: objective and subjective data.

The objective data will be reported on the front of the Maintenance Report (Figure 1), and is intended to aid in the evaluation of the prediction technique and highlight any problem encountered in the course of the maintenance task.

The subjective data will be entered on the rear of the report (Figure 2), and is intended to highlight those factors which indirectly might have an effect on the performance of a maintenance task.

The following instructions are intended to provide a uniform interpretation for the use of the form and provide a common base for the evaluation of all data presented on the Maintenance Report Form.

INSTRUCTIONS

The front of the report (Figure 1) is divided into basic areas which, for explanation, are coded A through K. Each area is oriented to obtaining a particular aspect of the total information required.

A. This area provides the basic information for identification of the report.

A1. Report Number: A number will be assigned to each Maintenance Report Form for the purposes of reference, each report will be numbered in consecutive order starting with number 001 and continued till the last report of the Drift Mission.

A2. Date: Indicate date when the maintenance action was initiated.

A3. Mission Time: Indicate the total hours into the mission when the failure occurred. The first hour will be defined as the hour on the day when the electrical power is turned on, on day of the commencement of the Drift Mission.

A4. Report Type: The two basic reports will be for scheduled maintenance actions (SCH) or unscheduled maintenance action (UNSCH). Unscheduled maintenance will be performed to restore an item to a satisfactory condition by providing correction of a malfunction which has caused degradation of the item below the specified performance. Scheduled maintenance will be the maintenance performed to retain an item in satisfactory operational condition by providing systematic inspection, detection, and prevention of incipient failures. Preventive maintenance will be either scheduled or unscheduled depending upon the requirements of the mission.

B. This area identifies the system, component, and operational use of the unit involved in the maintenance report.

B1. System: Identify the system on which the maintenance action is performed.

B2. Component: Identify the part on which the maintenance action is performed.

B3. Duty Cycle: Indicate the average period of operation during each 24 hour period.

Duty cycle will be reported as shown below:

Period of Operation in 1/10 of hour

Number of operations each 24 hours

4 / 6

If the equipment is in operation:

- Continuously enter letter C.
- Intermittently on a random basis, enter letter I.

If the equipment is not used during the initial phases of the mission, a second slash will be added, and the day of mission noted when the equipment was used.

4 / 6 / 12

Number of days into mission when equipment was turned on.

B4. Repair by: Indicate by whom the repair was accomplished.

C. Failure Description: Enter in this box a brief narrative indicating symptoms of the failure and how each failed part was identified. Use malfunction code (Figure 3) to aid in description. If scheduled maintenance, then description and scheduled maintenance task shall be entered in the space.

D. Cause: Indicate why part failed if known. Use malfunction code to aid in description.

E. Parts Replaced/Repaired: Indicate the part or assembly that was replaced or repaired in the maintenance action.

F. Tools Required: Indicate what tools where needed, and what tools were used but misapplied (e.g. a small bladed screwdriver where a large one should have been used, etc.)

G. Test Equipment: Indicate test equipment used to troubleshoot the failure during the maintenance task.

H. Troubleshooting Procedure: If possible, give an indication of how the failure was isolated, whether by trial and error, substitution, series of planned tests, or logical analysis.

I. Maintenance Time Analysis: Maintenance Prediction assesses the average man-hours of work to perform the required corrective and preventive maintenance tasks. These active maintenance tasks do not consider the effects on elapsed maintenance time due to logistics problems or administrative procedures. The active repair time estimate of corrective maintenance predicts the downtime due to active repair which is the result of a malfunction causing system downtime. The preventive maintenance time estimate, on the other hand, predicts the downtime due to preventive maintenance activities. The corrective maintenance action is divided into the following corrective maintenance tasks (each element of time will be recorded in tenths of an hour):

I1. Component: Indicate the parts removed to gain access or parts removed for repair.

I2. Prepare: This unit of time is defined as the time in which investigations are made to determine what procedures will be required to be performed to effect the maintenance task (e.g. reading manuals, procedures, and acquiring of all tools required for repair action.)

I3. Localize: The time required to locate the source of failure in a system.

I4. Access/Close: The total time to disassemble, displace, and replace unrelated equipment to perform checks on the unit in question.

I5. Remove/Replace: The total time to remove and replace the faulty unit.

I6. Isolation: The time required for diagnostic procedures to locate the parts/item which has failed.

I7. Repair: The time required to replace faulty element.

I8. Alignment: The time required to adjust elements of the repaired unit so as to effect the proper operation of the system.

I9. Test: The time required to perform necessary checks to verify that the equipment has been restored to satisfactory performance.

J. Total: The total reflex, the sum of all the time elements of the repair action.

K. Discussion: This space is set aside to allow for observation made as a result of the repair action. Comments relating to maintenance induced failure difficulty in repair or troubleshooting should be included, or the reasons for abnormally high value for repair time.

II. The rear of the Maintenance Report Form (Figure 2) is broken up into four basic areas. Each area is oriented so as to obtain a qualitative evaluation of the maintenance task.

A. This area will be used to evaluate the subjective information associated with the maintenance task. Each item has a box next to it, in columns A, B, and C. In each box a numerical rating of 0 to 4 will be entered. The rating system will be evaluated on the following paragraphs.

B. This area is used to enter the total sum of each column.

B1. Enter sum total of Column A.

B2. Enter sum total of Column B.

B3. Enter sum total of Column C.

B4. Enter the value of MTTR by using downtime nomograph (Figure 4) for known values of $\sum A$, $\sum B$, and $\sum C$.

C. This area will be used to evaluate working condition under which the maintenance task was performed. In each box, a letter will be entered to give a relative value of each factor. The letters to be used are:

N - Normal, Midway

O - None, Not in Cycle

H - High, Late

L - Low, Early

D. Use this area to amplify any ratings given.

MAINTENANCE REPORT FORM

SYSTEM B1 ____________________ REPORT NO. A1 ____________________

COMPONENT B2 ____________________ DATE A2 ____________________

DUTY CYCLE B3 ____________________ MISSION TIME A3 ____________________

REPAIR BY B4 ____________________ REPORT TYPE A4 ____________________

FAILURE DESCRIPTION C ____________________

CAUSE D ____________________

PARTS REPLACED REPAIRED E

TOOLS REQUIRED F

TEST EQUIPMENT G

TROUBLESHOOTING PROCEDURE H

COMPONENT I1	PREPARE	LOCALIZE	ACCESS CLOSE	REMOVE REPLACE	ISOLATE	REPAIR	ALIGN	TEST
	I2	I3	I4	I5	I6	I7	I8	I9
TOTAL J								

DISCUSSION K

Figure 1. Maintenance Report Form, Front

MAINTENANCE ANALYSIS (A1)

		A		B		C
1.	ACCESS EXTERNAL	☐	EXTERNAL TEST EQUIPMENT	☐	STRENGTH REQUIRED	☐
2.	LATCHES & FASTENER EXTERNAL	☐	TEST INTERCONNECT	☐	ENDURANCE REQUIRED	☐
3.	LATCHES & FASTENER INTERNAL	☐	JIGS & FIXTURES	☐	EYE/HAND COORDINATION	☐
4.	ACCESS INTERNAL	☐	VISUAL CONTACT	☐	VISUAL ACUITY	☐
5.	PACKAGE ACCESS	☐	ASSISTANCE OPERATIONS	☐	LOGICAL ANALYSIS	☐
6.	COMPONENT/MODULE ACCESS	☐	ASSISTANCE TECHNICAL	☐	MEMORY	☐
7.	PERFORMANCE INDICATORS	☐	ASSISTANCE SUPERVISORS	☐	PLAN RESOURCE	☐
8.	MALFUNCTION INDICATORS	☐			ALERTNESS	☐
9.	TEST POINT IDENTIFICATION	☐			CONCENTRATION	☐
10.	TEST POINT REQUIREMENTS	☐			INITIATIVE/INCISIVENESS	☐
11.	PART IDENTIFICATION	☐				
12.	ADJUSTMENT & REALIGNMENT	☐				
13.	TEST CONDITION	☐				
14.	FAULT DETECTION	☐				
15.	SAFETY PRECAUTIONS	☐				

TOTALS

Σ A	B1	Σ MTTR	B4
Σ B	B2		
Σ C	B3		

WORKING ENVIRONMENT

LIGHTING	C1
TEMPERATURE	C2
HUMIDITY	C3
NOISE LEVEL	C4
CONTAMINANT LEVEL	C5
TIME INTO CYCLE	C6
MISSION MODE STRESS	C7

DISCUSSION (D)

Figure 2. Maintenance Report Form, Rear

MALFUNCTION DESCRIPTION CODES - ALPHABETICAL LISTING

Code	Description
956	Abnormal Function of Computer Mechanical Equipment
931	Accidental or Inadvertent Operation, Release or Activation
127	Adjustment or Alignment Improper
651	Air in System
007	Arcing, Arced
103	Attack Display Malfunction
694	Audio and Video Faulty
693	Audio Faulty
652	Automatic Align Time Excessive
731	Battle Damage
710	Bearing Failing or Faulty
780	Bent, Buckled, Collapsed, Dented, Distorted, or Twisted
135	Binding, Stuck or Jammed
303	Bird Strike Damage
838	B Plus Incorrect
070	Broken
719	Broken or Frayed Bonding or Ground Wire
108	Broken, Faulty or Missing Safety Wire or Key

Figure 3. Malfunction Description Code - Alphabetical Listing Sample Sheet

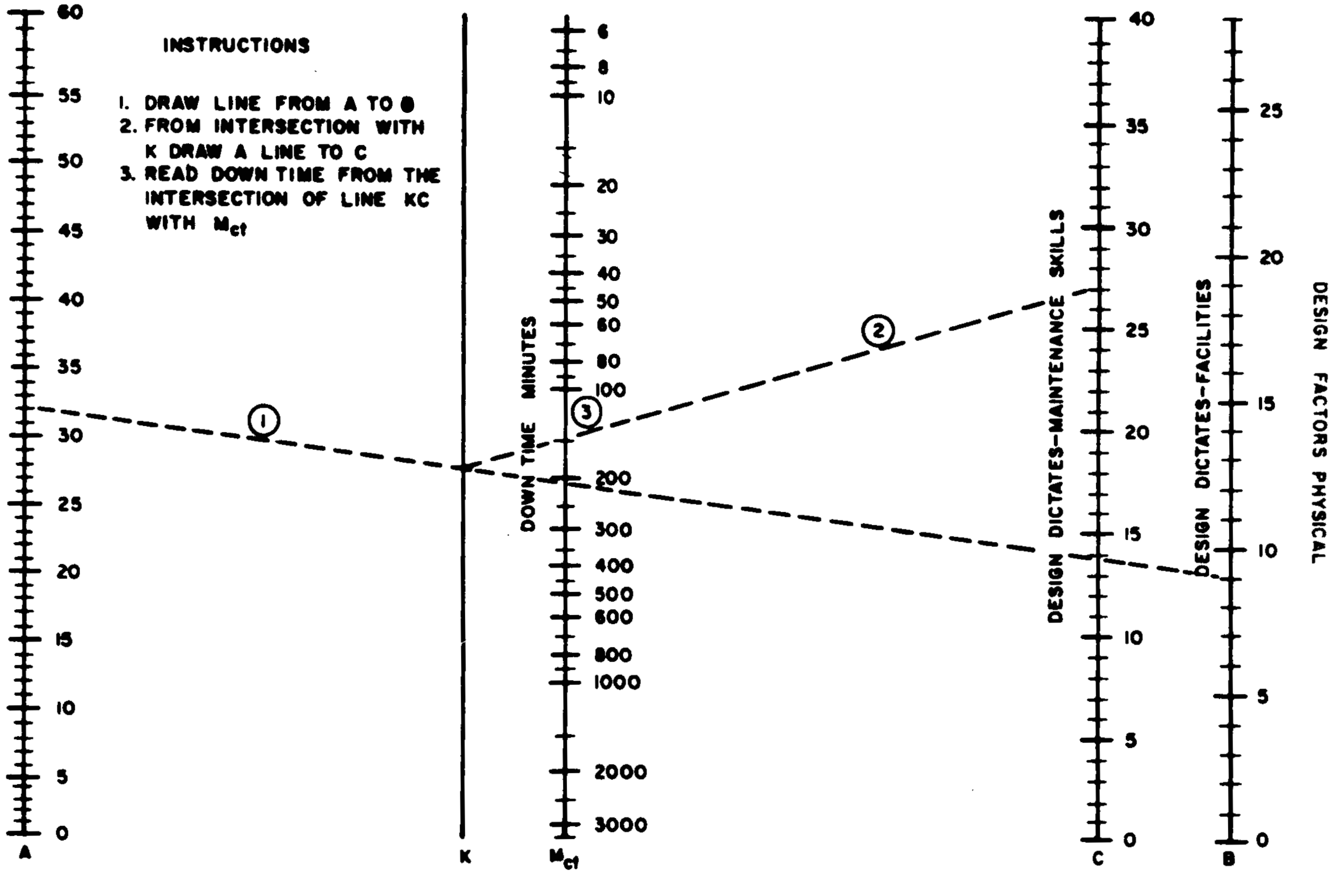


Figure 4. Downtime - Nomograph